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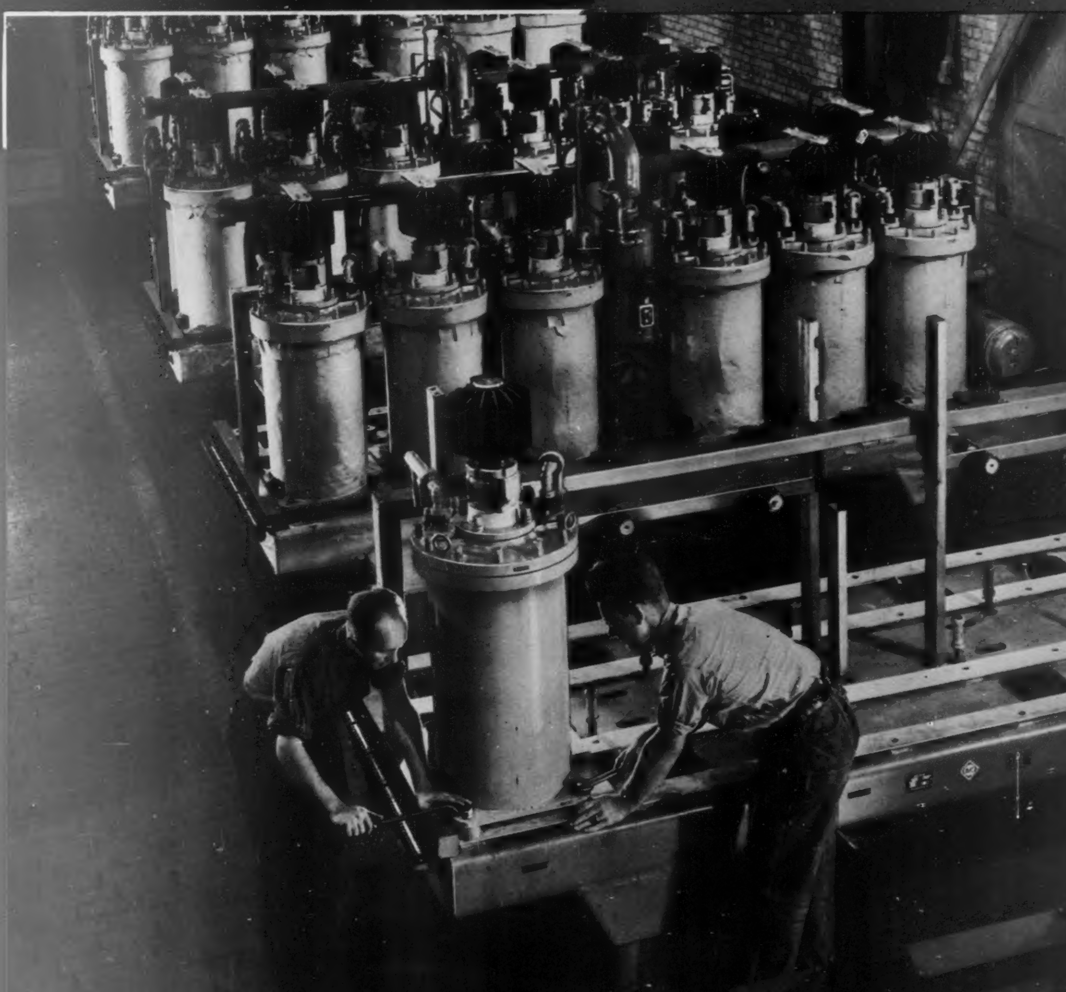
ELECTRICAL REVIEW

September • 1943



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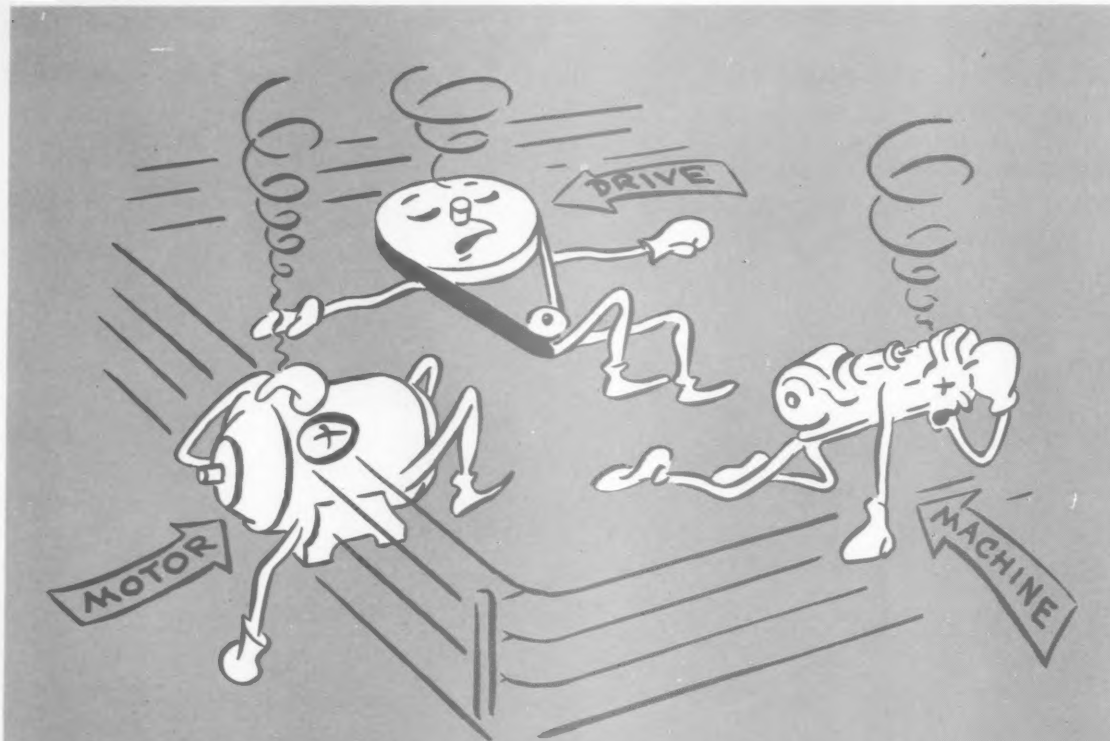

Once Misalignment starts 'em Fighting each other . . . the only Question is: Which will go First?

SPRUNG OR BROKEN shafts, burned-out bearings, overload failure—are cases of motor damage commonly caused by Misalignment. And the damage can occur in drive or driven machine, too. For when these elements are assembled in incorrect geometry, bending, breaking or excessive wear must result. *Something has to "give!"*

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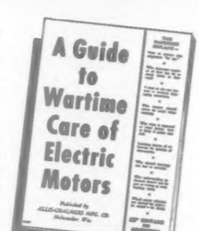

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ELECTRICAL REVIEW

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Material in this publication, where necessary, has been approved by proper government authorities.

A SUBSTATION—IN ONE PIECE

Once a new load center called for insulators, bolts, nuts, washers, transformers, wire, disconnects, circuit breakers, meters and hundreds of other items. Now engineers order just "one unit substation."

R. C. Odell

TRANSFORMER DIVISION • ALLIS-CHALMERS MANUFACTURING COMPANY

● At the close of World War I, the up-to-date distribution substation had large single phase transformers, feeder voltage regulators, oil circuit breakers and a maze of steel work to support the buses, metering transformers, fuses, switches, and lightning arresters. This expansive equipment was located as close as practical to the estimated center of its present and prospective load.

Field surveys and operating experience soon disclosed that single phase transformers could well be replaced by three-phase transformers. A three-phase transformer has advantages over a bank of single phase transformers in initial and installation costs, overall losses and space requirements, which overshadow the emergency capacity available in case of failure of one single phase transformer. This emergency capacity became of less importance because of the increasing reliability of the three-phase transformer and the development of the "network" system of paralleling secondaries, so that continuity of service could be maintained even though one three-phase transformer is out of service.

In addition, it was found that a number of small substations were more economical than a few large ones. This is because power can be transmitted at high voltage directly to a substation at the center of a load area from where the load is supplied through short secondary runs of copper. A few large substations on the other hand would have to supply several load areas apiece, necessitating longer secondary distribution circuits.

Regulators replaced

Substation design advanced again when tap-changing-under-load equipment was devised for three-phase transformers. This development took the regulators out of the substations and reduced the initial and installation expense, overall losses and space requirements. Metering outfits, consisting of current and potential transformers mounted in the same tank, were coming into use. These two steps reduced considerably the first cost of a substation as well as the time and labor required to install it.

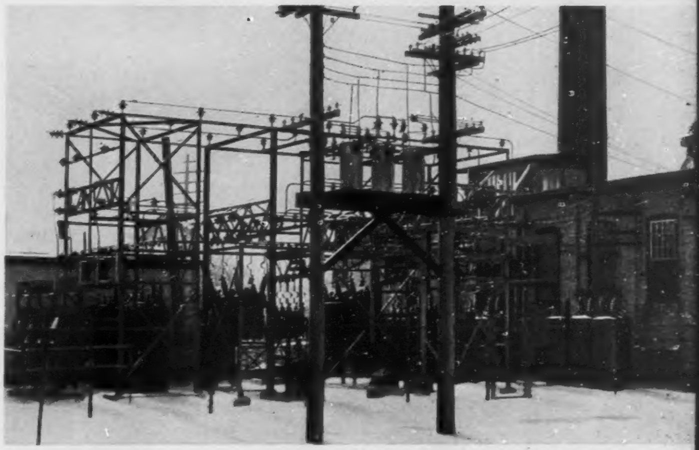
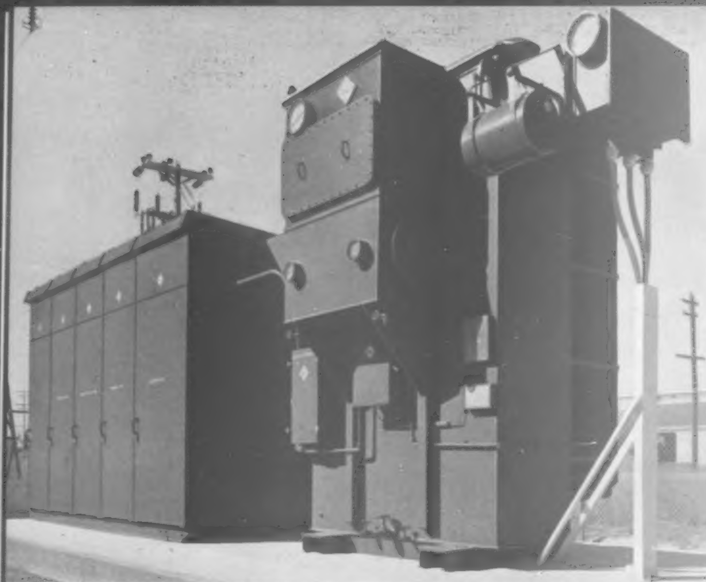


Fig. 1 — Old type substation, with a maze of buses, transformers, breakers, insulators, and steel framework.

The most recent development is a completely factory built and tested unit substation. The purchase of a substation is simplified; economy is gained by reducing first cost, installation expense and overall losses; and the unit takes less space. Factory fabrication of sections makes it possible to build an entire substation from one, two, or three sections that are easily joined together in the field and quickly put into operation, because all sections are already coordinated both mechanically and electrically.

The three general types of unit substations are multi-circuit substation, single-circuit substation and load-center substation. The first two are of fairly large kva capacities and are usually furnished with ratio-control equipment.

AT LEFT: Molded into the under-belly of the motor nacelle on a giant Boeing Flying Fortress is the aircraft supercharger, vital weapon of the Army Air Forces. Superchargers like this are mass-produced in one of the new Allis-Chalmers war plants.



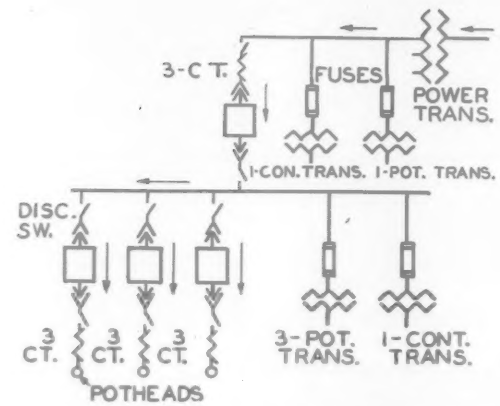
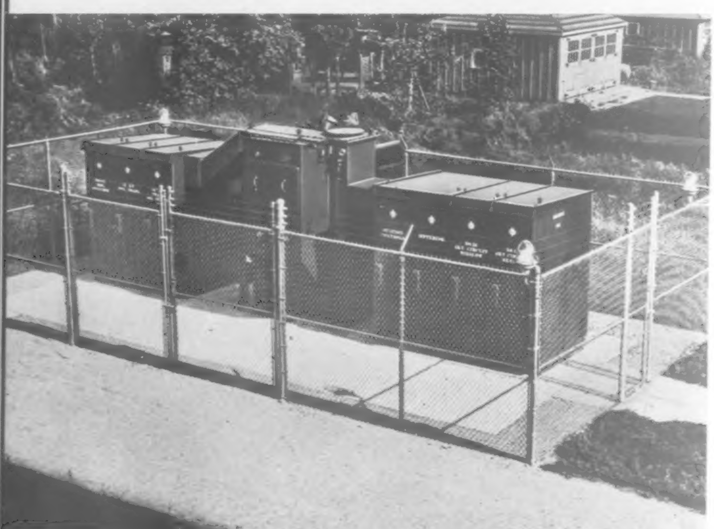


Fig. 2 — Single circuit substation, 3,900 kva, 33,000/4,330 volts, for feeding several load circuits from one transformer.



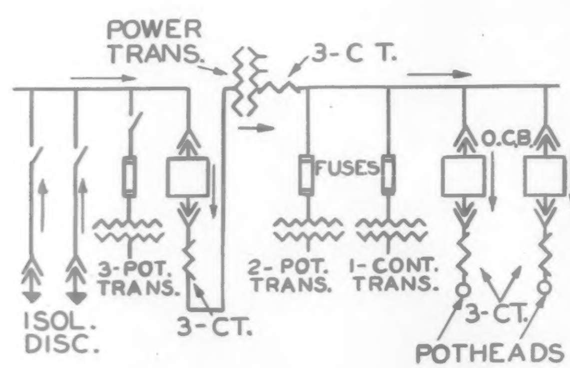
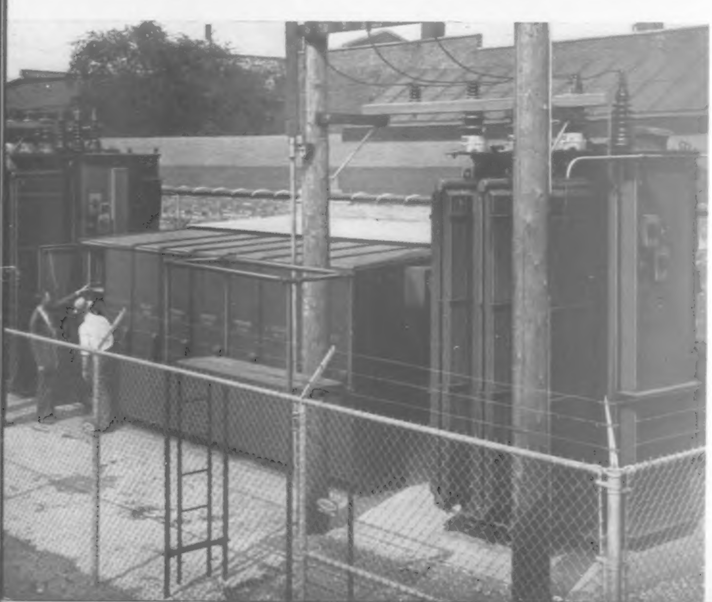


Fig. 3 — Single-circuit, 2,500 kva unit substation, with primary disconnects and circuit breakers. Voltage is 13,800/4160.



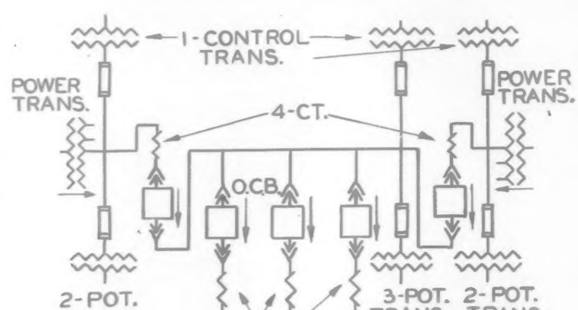


Fig. 4 — Either of two sources, or both in parallel, can supply the load from this 2,500 kva, 26,400/4,000 volt, single-circuit substation.

Transformers, switch houses

Most unit substation transformers are core type. The low voltage and high voltage windings are circular and braced to withstand heavy short circuit currents. By proper design, high resistance to lightning surges can be achieved. Transformer tanks are electrically welded, shot blasted and given three coats of paint. A heavy steel base is welded to the bottom of the transformer tank, and it is equipped with jack pads and grounding lugs.

Switch houses are of metal clad construction and completely weathertight. Circuit breakers are mounted rigidly on a structural steel framework; and instruments, meters and relays are mounted on hinged panels. All parts of the switch house are completely accessible for inspection by means of opening hinged doors or removable plates. A sturdy, light-running truck is available to simplify breaker removal. Control transformers are air cooled. The framework of the switch house is welded in a jig to provide accurate dimensions and similarity of units.

The case around the single circuit unit substation is also of weather-tight construction. Hinged doors and panels, and removable plates permit quick, easy inspection of all parts. The auxiliary transformers are mounted outside of the oil-filled transformer tank, and they are within easy reach for inspection. The potential transformers are mounted in a movable carriage in a separate compartment above the circuit breaker operating mechanism. After the door to this compartment is opened, the carriage may be withdrawn by hand, thereby disconnecting the high voltage source. This makes fuse inspection and replacement safer. The control instruments are flush mounted on panels. Lights and a convenience outlet are provided for after-dark operation and inspection.

Completely automatic units

Unit substations may be operated entirely automatically and with only periodic inspections. In some instances control equipment may be provided for remote operation of circuit breakers, indication of meters, changing of under-load taps and operation of other items, from a central location. Most stations may be put on the line manually and then run automatically.

Some unit substations in outlying areas are even equipped with telephones. At present the telephones are connected to the existing telephone network in the territory, but it is not hard to visualize that after this emergency, when electronic equipment becomes more available, carrier current systems will displace the ordinary telephone for this work.

APPENDIX

Multi-circuit unit substation

The multi-circuit unit substation consists of a three-phase, tap-changing-under-load transformer, usually 1,000 to 10,000 kva, connected by throats to either high voltage or low voltage (or both) metal-clad switchgear containing the necessary oil or air blast circuit breakers, buses, metering equipment and automatic control devices.

Three general arrangements of transformers and switchgear are used, with variations and additions available to adapt these three schemes to unusual conditions. The most common arrangement is one transformer and one switch house, as shown in Fig. 2a. Another popular arrangement (Fig. 3a) has a transformer with two switch houses, one for the low voltage circuits and the other for the high voltage connection. The third arrangement (Fig. 4a) has two transformers which may be operated either in parallel or singly, with a switch house between them.

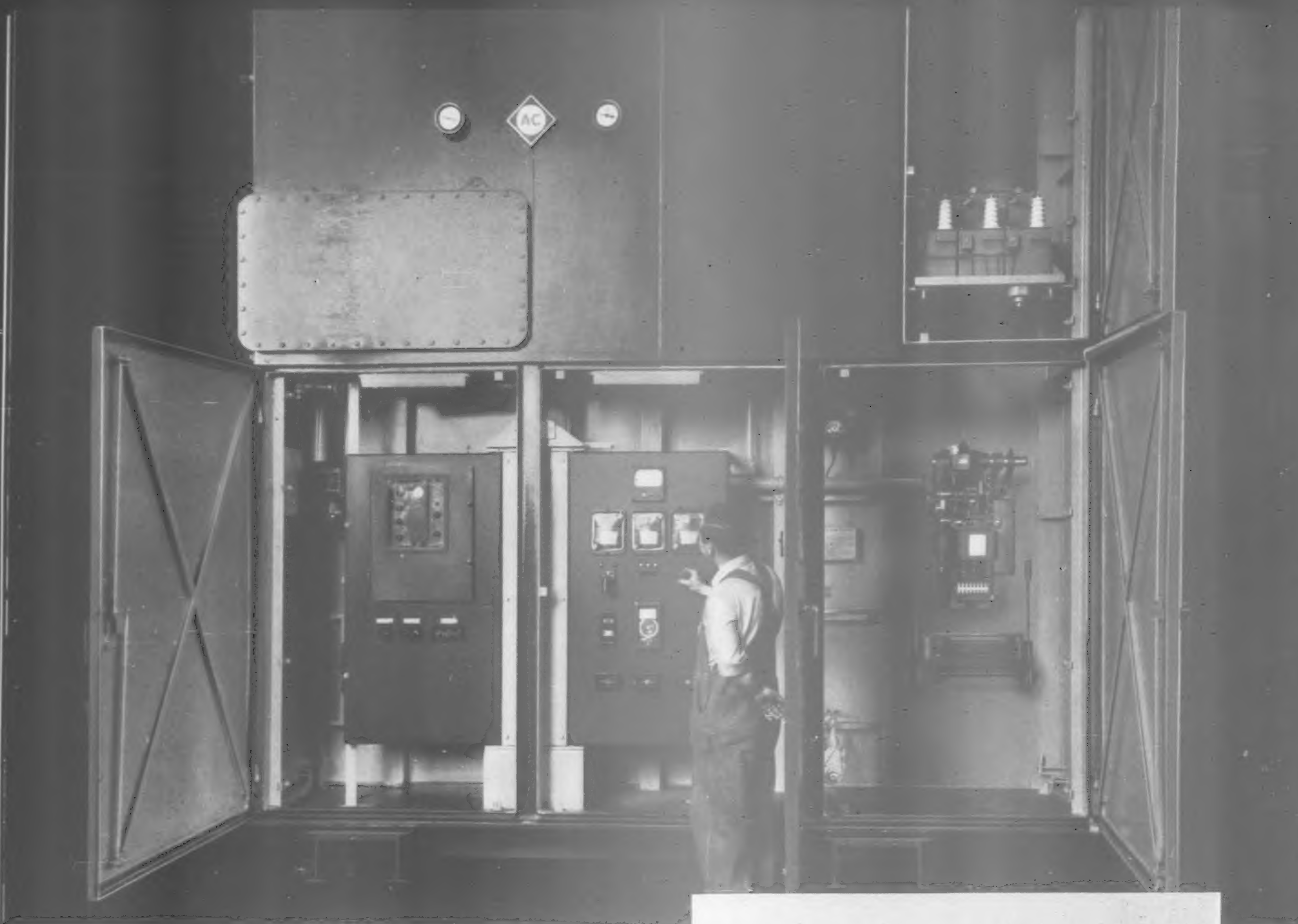
One-line diagrams graphically represent the equipment in these unit substations in Figs. 2b, 3b, and 4b. Disconnect switches, oil circuit breakers, fuses, transformers and potheads are shown, but the meters, relays, and other connected equipment are not shown. The circuit breakers are of the vertical lift type so that they can be easily removed from service for inspection and maintenance. As shown, some are isolated by disconnects and others are not, depending upon the application of the unit substation.

Multi-circuit transformers

The potential transformers in Fig. 2b between the main low voltage circuit breaker and the power transformer are used for a voltage source for the reclosing relay and the contact making voltmeter for the automatic control of the line voltage by under-load taps in the power transformer. The control transformer in that line supplies auxiliary power for the lights and space heaters in each unit, main low voltage circuit breakers, and the tap-changing mechanism motor. The current transformers supply ammeters, back-up overcurrent relays, watt-hour meters, and the line drop compensator in the automatic voltage control circuit. On the other bus the potential transformers supply a watt-hour meter, recording voltmeter and test switches for a portable demand meter. The control transformer supplies the closing and trip circuit for the three load oil circuit breakers.

In Fig. 3b, the load current transformers, together with the secondary circuit potential transformers, provide power for the type CR directional relay to prevent reversal of power flow. In addition, one potential transformer supplies the contact-making voltmeter. The control transformer supplies power for the lights and space heaters in all compartments, the closing and trip circuits for the two low voltage oil circuit breakers, and the mechanism motor. The potential transformer in the high voltage circuit is for potential indicating lights and an overvoltage relay. The current transformers supply the line drop compensator and back-up overcurrent relays.

Two transformers feed three load circuits in Fig. 4b. The loads may be fed by either transformer or by both transformers in parallel. The control transformer between each power transformer and its line circuit breaker supplies space heaters, the closing circuits for these breakers and the tap changing motors. The current transformers supply wattmeters, the line drop compensator and directional overcurrent relays. The three sets of potential transformers supply the contact-making voltmeter on each transformer, reverse phase relays, a synchro-verifier, undervoltage relays, directional overcurrent relays, indicating voltmeters and wattmeters. The control transformer between the two main breakers supplies the trip circuit for these breakers and the closing and trip circuits for the three load breakers.



Current transformers in the load lines of each substation are used for overcurrent protection through the overcurrent relays, as well as for indicating or recording ammeters.

The single circuit substation

The single circuit unit substation consists of a three-phase tap-changing-under-load transformer, usually 1,000 to 4,000 kva, mounted in the same case with a single circuit breaker, and metering and control equipment. The transformer, tap-changing-under-load equipment, the vertical lift (or fixed) oil circuit breaker, auxiliary transformers, meters and relays are mounted in separate compartments. A single circuit unit substation is shown in Fig. 5a, with its doors open to illustrate the compactness and accessibility of the installed components. A one line diagram (Fig. 5b) shows the circuit arrangement. The current transformer supplies an ammeter, overcurrent relays, the trip coils on the circuit breaker, and the line drop compensator for automatic voltage control. The potential transformer is for potential-indicating lights, a trip coil on the circuit breaker, and a potential circuit installed remote from the unit. The control transformer supplies lights, a convenience outlet, the closing and trip circuit for the oil circuit breaker and mechanism motor.

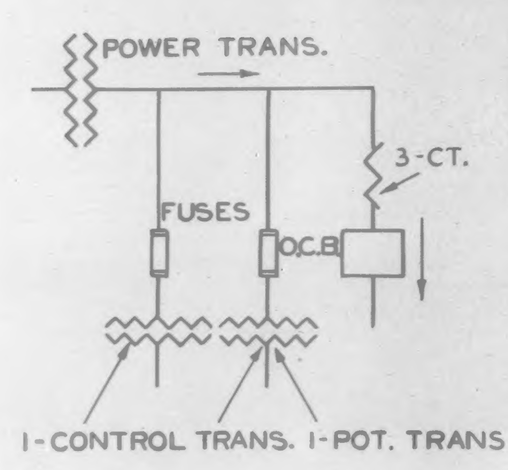


Fig. 5 — Panels and doors open to give quick and easy access to working elements of a 3,000 kva, single-circuit unit substation.

PUTTING THE CONDUCTOR WHERE THE CURRENT IS

Dragging cables between electrical machines is work! It is much easier to put in a pre-fabricated bus run and just bolt the connections, in the manner made possible with bus run designs like those described below.

D. K. Steidinger

SWITCHGEAR DIVISION • ALLIS-CHALMERS MANUFACTURING COMPANY

"Just provide enough circular mils to carry the amperes," is the usual solution to conductor and bus problems. That works, too, for direct current conductors and even alternating current buses up to approximately 2,000 amperes capacity. Alternating currents concentrate along the outside of conductors and shift away from or toward adjacent conductors! It is then that the engineer can save money as well as hundreds of pounds of critical material by simply placing the conducting material where the current will go through it.

Before a bus can be designed, it is necessary to know the continuous and momentary current rating, temperature rise, type of enclosure and conductor covering, voltage for which it is to be insulated, and the system frequency. It seems like these are enough specifications for a transformer or generator, but each factor is a key to the design of economical bus runs.

Distribution of current

In general, an a-c bus will be more complicated to design than the ordinary d-c bus because current distribution in the cross-section is not uniform, as a result of self inductance within a conductor. This is called skin effect. The flux linkages from self inductance are greatest in the center, so the current is forced to flow principally near the surface, which is the path of least impedance. As a result, in an isolated conductor the instantaneous currents across the cross section will be out of phase, and their arithmetic sum is greater than the resultant current.

A nearby conductor carrying current will also distort the current distribution within a conductor because of the mutual inductance. With conductors carrying current in opposite directions, this proximity effect causes concentration of current in the section of the conductor nearest the other conductor. Darker regions in Fig. 1 represent greater current concentration caused by skin and proximity effects in two conductors. This illustration suggests that removing the center of the conductor will save material and not greatly affect the current carrying capacity.

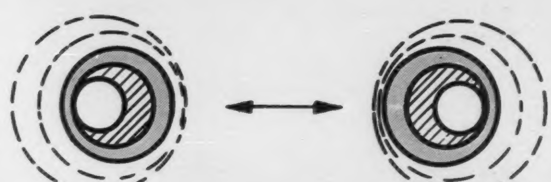
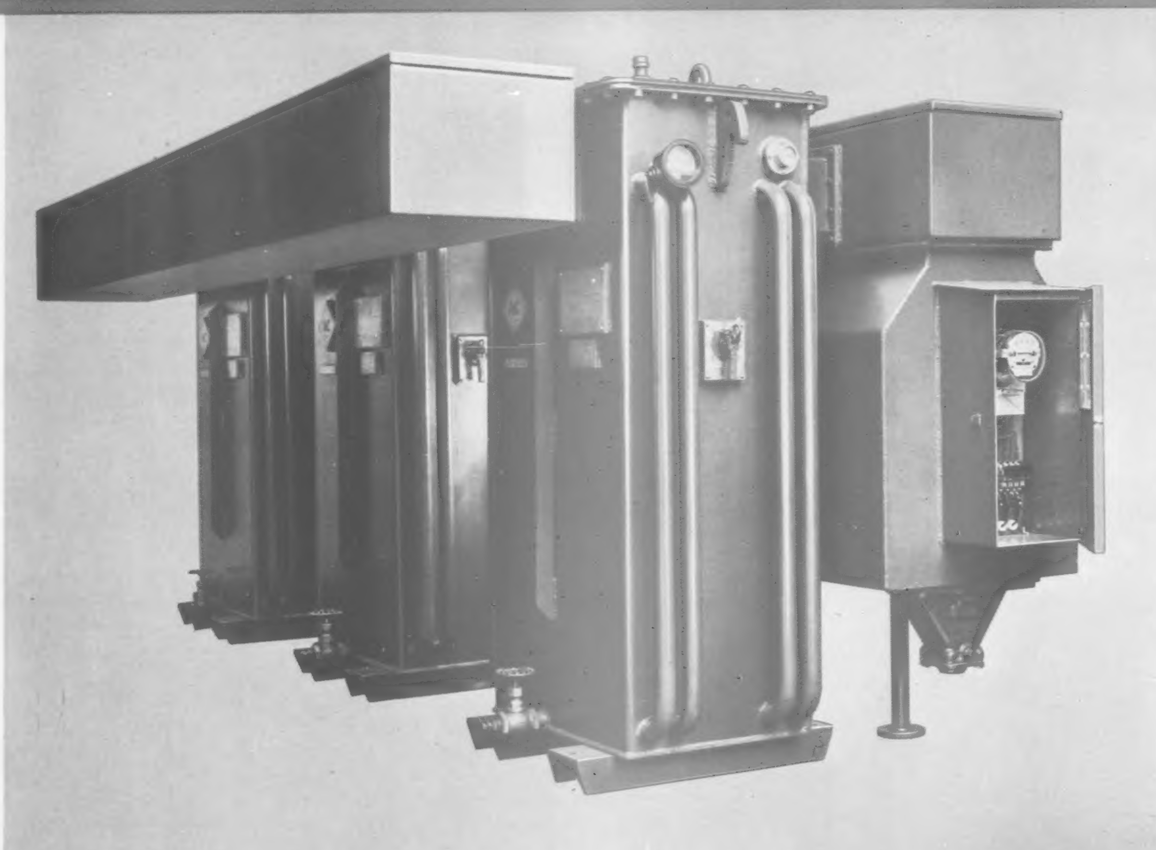


Fig. 1 — Current concentration areas in two conductors. Dark areas represent higher density.

Experiments have shown that the optimum wall thickness decreases as the frequency of the current increases. This seems only natural when it is remembered that constant direct current (zero frequency) conductors can be solid, and that inductance effects increase with the frequency.

Magnetic effects

The dotted lines in Fig. 1 represent the magnetic field about the two conductors, resulting in a force between them. The magnetic field from normal currents will induce in the surrounding magnetic materials both magnetism and currents which cause heating. Reinforcing steel members in concrete have sometimes been removed to prevent their overheating when they are located near heavy load currents. Materials enclosing bus runs must be such that inductive heating will not be excessive; hence, steel enclosures are unsatisfactory for three phase bus runs when the current exceeds approximately 2,000 amperes.



During short circuits on a system, tremendous forces are exerted between conductors, and these forces are the principal factor in determining the number and size of bus supports required. The bus supports must also be so located as to prevent natural resonance from frequency or other causes.

Materials

Copper and aluminum are usually used in bus conductors. Silver has been given much attention during wartime because it is abundant and has better conductivity than either copper or aluminum. Previously, silver's higher cost eliminated its use. However, skin effect is less with greater resistance in a given volume of the material, so silver loses some of its desirability compared to copper and aluminum in a-c application. Direct current buses have no skin effects, so silver is being used there.

For equal resistance, aluminum requires a greater cross section area which will have greater structural strength but less weight than copper. In spite of this, copper is still most commonly used because of its general electrical and mechanical characteristics.

Temperature rise

Only when buses carry many thousand amperes at low voltage do voltage drops become a consideration. Then, of course, a few volts may mean a high ratio of energy loss to energy transmitted. Ordinarily, a design ample for the temperature limits reduces the voltage drop to a negligible value.

The heat generated in the conductor must be dissipated to prevent it from reaching a temperature which would finally cause physical damage to the conductor or injury to surrounding material. Temperatures are held much lower than this to prevent the oxidation at bus joints from becoming excessive and increasing the total bus resistance, resulting in a vicious circle of increasing resistance and temperature. Even within the established temperature limits it is desirable to silver plate all contact surfaces of copper buses. Aluminum conductors require a special treatment which excludes air when the joint is made, thus preventing oxidation. A silver surface oxidizes into silver oxide which has resistance nearly as low as silver itself, and thus bus characteristics do not change much.

UPPER LEFT (Fig. 2) — Bus runs from a transformer to a 1,000 kw rectifier in a steel mill.

LOWER LEFT (Fig. 3) — Bus runs correct both high and low sides of this bank of three 75/100 kva single-phase transformers.

RIGHT (Fig. 4) — Top view of bus runs in Fig. 3, with covers removed to show connections.

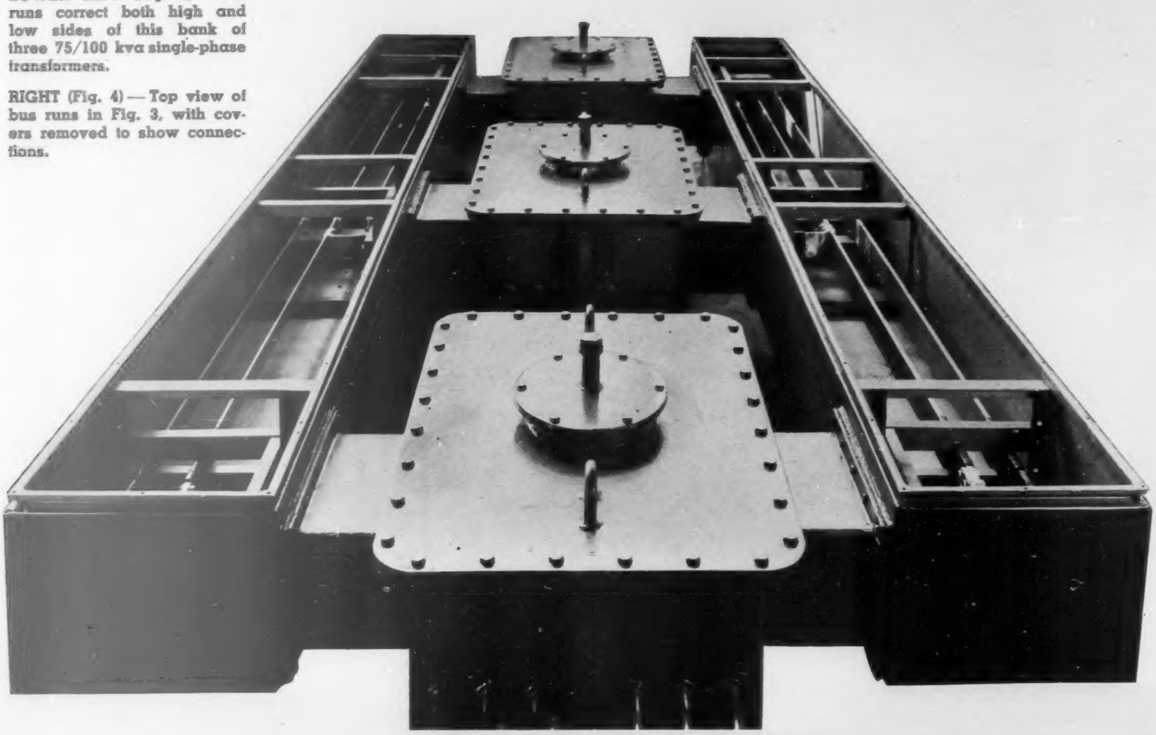


Fig. 5 — Open view of a bus run rated 15 kv, 4,000 amperes full load, which can momentarily withstand 130,000 amperes. Segregated phase construction.

The temperature during a momentary short circuit current becomes very high, and allowance must be made for the maximum lengthwise expansion. Changes in length can be accommodated by expansion joints of laminated or mesh connections.

Heat dissipation is affected by many physical factors in bus construction. Several conductors per phase will carry more current at a specific heat than an equivalent cross section area in one conductor, because more surface area will radiate more heat. A dull surface, painted or discolored, will radiate much more heat than a polished one, so the mere oxidation of a bare bus will give it greater current carrying capacity.

Bus protection

The simplest buses are bare conductors mounted in the open on insulators. Safety and service considerations usually require conductor coverings for indoor buses above 5 kv rating, and often for applications below that service voltage. Enclosures give further protection, and for compact outdoor buses they are very desirable. The most elaborate design is the isolated phase construction in which each conductor is enclosed in a separate compartment.

Bus enclosures can be made from a great variety of materials, both metallic and non-metallic. The latter usually are poor transmitters of heat, so ventilation is required. Metallic enclosures will transmit heat directly through their walls, but they must be selected so as to avoid magnetic heating.

Uses for bus runs

Bus runs have many uses; the more common being connections between a generator and switchgear or between transformers and switchgear. Buses are also very useful for connecting rectifiers to their transformers (Fig. 2), thus eliminating numerous cables. An unusual application is shown in Figs. 3 and 4 where buses form both the high and low voltage connections for a bank of three single phase outdoor transformers, thus, replacing connections which normally require expensive and awkward structures.

A large generator is connected to switchgear with the bus in Fig. 5. This bus is rated 4,000 amperes continuous, 15 kv insulation for 6.6 kv service voltage, 50 cycles and it can momentarily carry 130,000 amperes. The phases are segregated, and metal enclosed indoor construction with a 45C allowable rise is used. The hollow square copper conductor is inherently rigid, providing the backbone of the assembly, and it is so mounted on insulators as to allow easy expansion. The metal enclosure as well as the support members are made of non-magnetic metal to eliminate inductive heating. This bus is the only practical way in which such a large quantity of power could be transmitted under the particular conditions.

A standard bus run rated 1,200 amperes, 15 kv, 50,000 amperes for one second, having covered conductors and a steel enclosure is shown in Fig. 6. Such a bus is often used between a transformer and switchgear in place of long cable runs.

Conclusion

Bus design requires more than a casual investigation and a rule-of-thumb specification. An interesting problem of making ample provision for all factors of economy, temperature rise, electrical adequacy and mechanical adequacy presents itself in the modern high capacity bus.

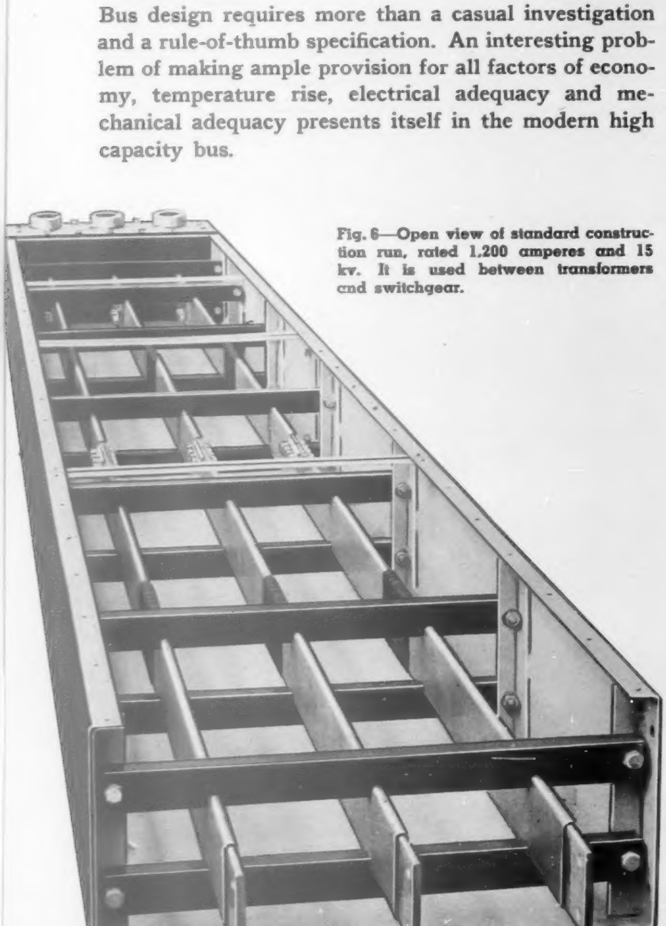


Fig. 6—Open view of standard construction run, rated 1,200 amperes and 15 kv. It is used between transformers and switchgear.

New Motor Starter For Industrial Uses

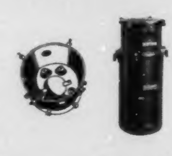
The Type H motor starter, built to withstand severest operating conditions, is now available for industrial applications. Designed for low first cost, the new starter is a metal-enclosed structure with front swinging doors and removable rear plates. High interrupting capacity disconnecting-type fuses are used in combination with a heavy duty oil switch.

Type H starters have been developed for both induction and synchronous-type motors rated up to 700 hp at 2,300 volts and 1,250 hp at 4,600 volts, 3-phase, 60 or 50 cycles. Their usages cover: full or reduced voltage starting, dynamic braking, reversing.

Short circuit protection up to 150,000 kva at 2,300 volts and 250,000 kva at 4,600 volts eliminates the need for a back-up breaker within these kva ratings. Disconnecting type fuses combining high interrupting capacity with fast-clearing action, hold short circuit currents to safe values which do not damage the control. Fuses operate only under actual short circuit conditions and will not blow unnecessarily.

Type H starters protect motors from sustained overloads, locked rotor condition, single phasing and overloading from too frequent starting by means of thermal overload relay accurately calibrated.

Distribution Transformer Has Welded, Turret-Top Terminal Compartment



Streamlined, turret-top construction for small distribution transformers now makes it possible to obtain a completely enclosed, safe terminal compartment which is much more compact and lighter in weight than the ordinary large conduit compartment. This construction is available in smaller size, round tank distribution transformers where relatively low voltages are involved.

The new terminal compartment is provided by welding a housing directly to the transformer cover and installing high and low voltage conduit nipples. No new parts are required, nor is any additional floor space needed. Fabricated with automatic seam-welding machinery, the turret-top construction is uniformly neat and light weight.

By removing the turret cover, stud bushings are easily reached. And for maximum safety to the operator when making periodic wartime inspections of the interior, or changing low voltage connections, insulating caps are provided over the high voltage connections.

For further, more detailed information regarding these new products, write the Editors of ELECTRICAL REVIEW.

WHAT FLUX DOES IN A MACHINE

In simple, non-mathematical terms, here's the story of how magnetic flux affects the performance of motors and generators, with notes on how to get special characteristics.

V. B. Honsinger

ELECTRICAL ENGINEERING DEPARTMENT • ALLIS-CHALMERS MANUFACTURING COMPANY

● A motor or generator has three basic electrical parts: the magnetic circuit, electrical circuit, and the insulation. Of the three, the magnetic circuit has the greatest effect on the performance of the machine. Since a consideration of flux distribution is involved in almost any electrical problem, a knowledge of the magnetic circuit and the flux components of industrial machinery, such as induction motors and d-c machines, is generally quite helpful.

In order to understand their elementary basic relationships, the flux in an induction motor may be divided into these components:

1. Mutual flux
   a. Stator mutual flux
   b. Rotor mutual flux
2. Leakage flux (stator or rotor)
   a. Slot leakage
   b. End-connection leakage
   c. Differential leakage

The mutual flux (Fig. 1) is the flux which links the windings of both stator and rotor and thereby transfers energy from one winding to the other. During normal operation the value of the armature (stator) current is mainly determined by this large mutual flux, because of the reactance it has on the stator coils. The resistance and leakage reactance come in as secondary items.

Leakage flux links only the winding that causes it. It has nothing to do with transferring energy except for its small effect in limiting the stator or rotor current, but it does play an important role. Note that the leakage fluxes of the stator and rotor exist in different magnetic circuits, as shown in Fig. 1, while the mutual fluxes exist in the same magnetic circuit. The logical conclusion is that, should the rotor mutual flux become large enough to cancel out practically all of the stator mutual flux, the leakage fluxes cannot cancel since they exist in different magnetic circuits.

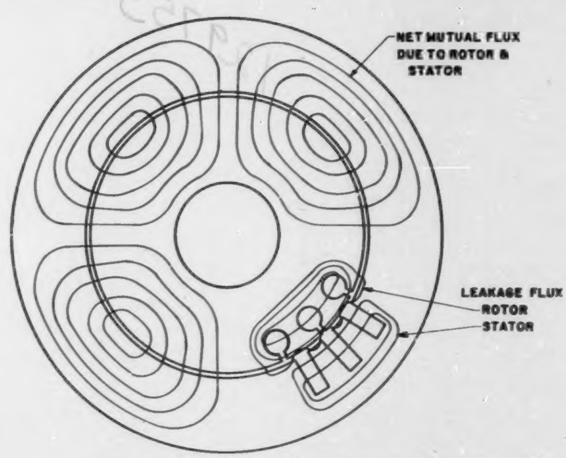


Fig. 1 — Field of a four-pole induction motor.

This condition occurs at the first instant, when the motor begins to rotate. The starting current, therefore, is very closely dependent upon only leakage reactance and, consequently, is much larger than the normal running current. This large current causes high voltage drops in the supply system and results in many disturbances, the most common being light flicker.

To get lower starting current, it is logical to raise the leakage reactance by increasing any or all of the three leakage reactance components. The most effective way is to design a slot with plenty of flux surrounding it. Of the three types of slot shapes in Fig. 2, slot A has more reactance than slot B because its deep, narrow shape permits more flux to link the current, resulting in high reactance. Slot A will be used on a low starting current, low starting torque motor, while slot B will be used when there are no restrictions on starting current and a high starting torque is desired.

It is possible to combine both designs of slots and have a high starting torque, low starting current motor

AT LEFT: One of the largest d-c units ever built, weighing 500,000 pounds, this mighty motor will drive a blooming mill to produce steel for victory. By means of a special control, it is capable of reversing itself in less than 1½ seconds. At its peak, the motor can produce 19,000 horsepower, and 7,000 horsepower in normal operation.

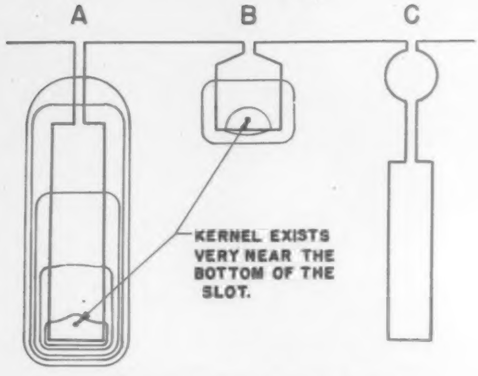


Fig. 2 — Sketch of the flux in common slot shapes.

by using slot C, which is a typical slot for double cage rotors. The bottom portion of this slot corresponds to a high reactance slot while the top portion corresponds to a low reactance one. The cross-sectional area of the top hole is purposely made small to increase the resistance of the top cage.

High rotor resistance means high starting torque. During starting, when the rotor frequency is high, the current tends to flow in the top, high-resistance cage, producing a large torque from relatively low starting current. As the motor approaches normal speed, the rotor frequency drops and the mutual flux spreads around the bottom cage. The low resistance bottom cage does not cause a large I^2R loss and thus contributes toward making the motor efficient in normal operation.

D-C motors and generators

The flux in a d-c machine may be divided into these three components:

1. Main field flux
2. Armature field flux
3. Interpole flux

During operation all three fluxes exist simultaneously and cannot be thought of as being separate entities. However, for illustrating the space distribution of the three components, Fig. 3 shows each component acting alone in a bi-polar, single interpole, shunt wound machine.

The part of the total flux which is of most interest exists in the airgap beneath the main field poles. This flux passes through the teeth—that is, perpendicular to the conductors—and thus is voltage-generating flux. The effects of the armature and interpole flux in changing either the direction or magnitude of the main field flux are called armature and interpole reaction.

It is easy to see that the armature flux in the airgap adds to the main field flux on one side of a pole face and subtracts from the other side (Fig. 3). The interpole flux is similar in its action except that, in the case shown, it adds to one complete pole and subtracts from the other complete pole. Because of saturation, not as much flux is added to the main field flux as is subtracted, and thus the net full load flux — the sum of all three components — is less than the no load flux.

In most cases, the effect of armature and interpole

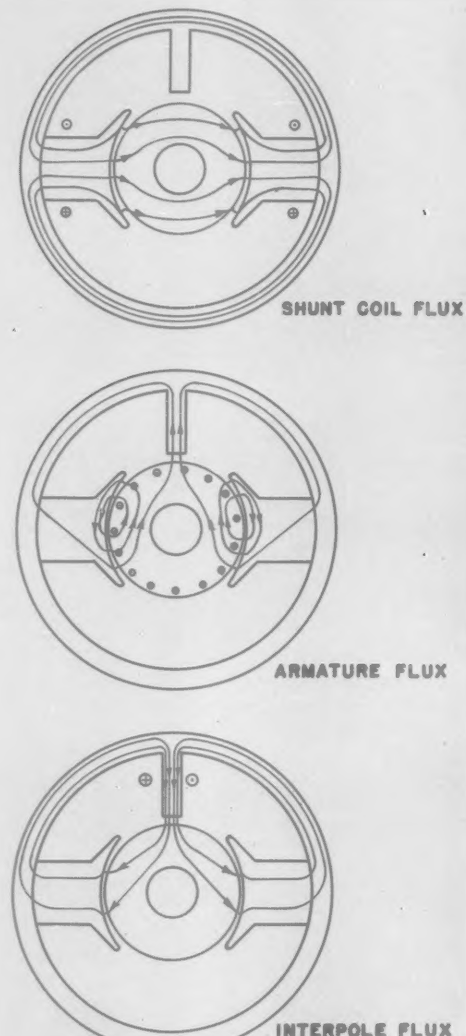


Fig. 3 — Sketch of the three flux components acting alone in a d-c machine.

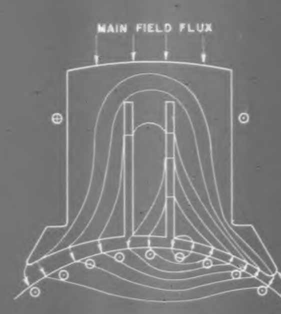


Fig. 4 — Special pole with barrier to armature flux.

reaction can be determined quite closely from previous tests on similar machines. In a constant speed motor this effect is not a critical factor, except when a speed or voltage regulation of special nature is desired.

Variable speed motors

However, many d-c motors are variable speed and drive variable torque loads such as fans and centrifugal pumps. In such a case the armature current varies approximately as the cube of the speed. To drive a motor at a higher speed, the field current (or main field flux) must be reduced. Thus at the high speed, a condition of high armature and interpole flux with low main field flux exists in the machine. In certain instances, where this effect is pronounced, the machine will start automatically increasing its own speed and become unstable.

To counteract armature and interpole reaction, all variable speed pump and fan motors are wound with a light series field in addition to the shunt field. The series field flux, like the armature and interpole flux, varies with load current, and strengthens the main field when armature current increases. Also as load increases, the armature and interpole fluxes weaken the main field flux, so the net change is too small to make the motor unstable.

The designer incorporates another stability factor into his design by making the main pole airgap longer than usual on motors that have wide speed ranges. Since both interpole and armature flux must pass through the main pole airgap, less interpole and armature flux will pass through if this gap is increased. However, the main field flux at a given speed is independent of the length of the gap, other things being equal. Therefore the main field flux is not weakened nor distorted as much as it would be with a smaller gap, thus making the motor less sensitive to load current. The ampere turns on the main field will, of course, have to be increased to give the required flux in the longer gap.

Some specifications for d-c generators require that the voltage versus line-current curve be a straight line instead of the usual humped curve. One way to accomplish this is to make the main pole gap larger where the armature flux adds to the main field flux and smaller where it subtracts, thereby reducing distortion of the main field. Furthermore, the field poles are designed with a barrier to armature flux such as two deep slots in the field pole, through and around which the armature flux must pass (Fig. 4). This type of pole reduces armature flux and contributes to straight line voltage regulation.

Stability of a generator is based upon voltage. The operating point of a self-excited generator is the intersection of the load saturation curve and the resistance line. The slope of the resistance line is determined by the sum of the resistance of the shunt field and the part of the rheostat that is in the shunt field circuit. When the resistance line intersects the load saturation curve at a point above the knee, as at point A, in Fig. 5, a definite operating point is established. On the other hand, as the rheostat resistance is increased to lower the voltage, the resistance line rotates about the origin and when the intersection falls on the straight portion of the saturation curve, as at point B, the generator may show a fluctuating voltage, since there is no definite point of intersection.

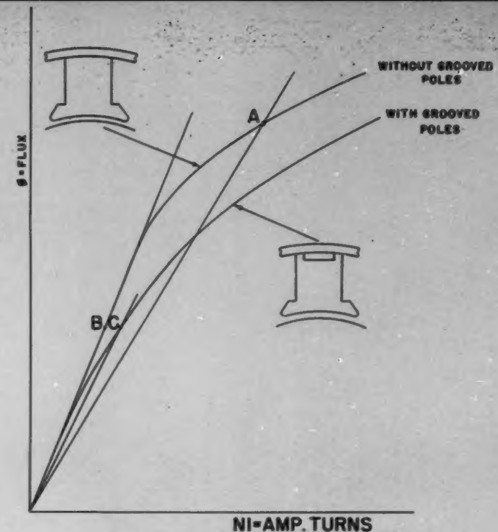


Fig. 5 — Effect of grooved main field poles on the saturation curve.

To insure stability at low voltages, the designer introduces curvature to the saturation curve just below the low voltage operating point. One way to do this is to install a grooved main field pole (Fig. 5) instead of the solid pole. The two narrow ridges left by the groove saturate quickly and result in a saturation curve having an extra knee at low flux densities in addition to the one at relatively high flux densities. As a result, the operating point C is on a definite intersection between the resistance line and the grooved-pole saturation curve. This will insure good voltage stability at low voltage as well as at normal voltages.

The main function of interpole flux is to insure sparkless commutation. The interpole magnetic circuit includes the yoke, main field pole, and core. In a variable speed motor, as the main field flux is diminished to get higher speed, the interpole flux increases because of the increased permeability of its circuit. This increased interpole flux often causes the machine to spark at the high speed and may even cause instability although operation will be perfectly normal at the low speed.

To improve this condition, it is necessary to increase the interpole gap so as to reduce the interpole flux at the high speed. Just how much the gap should be increased is difficult accurately, because of the several factors involved in determining the resultant effective interpole flux. Where motors have a wide speed range, it is often necessary to wait until the motor is on test before making final adjustment of interpole gap to insure the best operation over the speed range. This is usually accomplished by adjustment of shims, provided behind the interpole for this purpose.

This discussion is non-mathematical in nature and can only give a qualitative conception of the various flux components and their relation to each other. The flux components in reality are fictitious since the magnetic circuits involved are functions of a variable permeability. Nevertheless it is convenient to separate the flux into components to make it easier to visualize the part each plays in the performance of the machine.

ON FOLLOWING PAGES: Low pressure spindle with all-welded rotor, in process of construction, for one of the largest tandem-compound steam turbines ever built. This impulse reaction type turbine is rated at 147,000 kw, 1800 rpm.


109753

THE NINETEEN BASIC U. S. INVENTIONS

II. TRANSPORTATION *

Transportation is movement, and moving objects have inertia and resistance. Therefore, each famous inventor in this field succeeded only after applying basic engineering technique and critical research.

Miles Henninger

PATENT ATTORNEY • ALLIS-CHALMERS MANUFACTURING COMPANY

● Unless life is to be conducted on the basis of an isolated and makeshift self-sufficiency, it is necessary to provide for the transportation of goods and people. United States' inventions like the steamboat by Fulton, the air brake by Westinghouse, the airplane by the Wright brothers, vulcanized rubber by Goodyear, and oil cracking by Burton, have changed world economies and the lives of whole nations. Unfortunately, such inventions are even more effectively used in war than in peace, as is the case with all peaceful devices adapted to war purposes.

Fulton's Steamboat 1807

The steamboat is an example of the accomplishment of individual effort and ingenuity in the face of disaster and man-made obstacles. William Henry, a Lancaster gunsmith, built a boat driven by a Watt steam engine. John Fitch of Philadelphia tried a boat with steam-engine driven oarlike paddles along the side and at the stern of a boat. Fitch ran his steam-oar boat as a ferry between Philadelphia and Burlington during the entire summer of 1790, but even Ben Franklin thought Fitch was crazy. He could get no financial aid whatsoever and finally committed suicide.

William Symington built a boat in Scotland in 1801, powered by a Watt engine and driven by a paddle wheel in the stern, but it was abandoned. John Stevens, with the financial aid of Robert R. Livingston, also built and tested a steamboat in 1798 and he even tried the screw propeller.[1] Fulton and Livingston had, however, obtained a monopoly for navigation on the Hudson River, and Stevens worked on a sea-going boat which made the first trip from New York to Philadelphia in 1808.

Fulton was born (1765) in Lancaster, Pa., where he received an ordinary elementary education. He grew up among the mechanical work shops which supplied the Revolutionary armies with equipment and munitions, and he early displayed ability in the usual boyish tinkering with mechanical devices. He also developed a talent for drawing, which took him to Philadelphia where he designed carriages, machinery, and buildings. His drawing ability led him to study painting under Benjamin West in London, as a protege of Benjamin Franklin; and later under Joel Barlow in Paris. While in England, Fulton became familiar with the various uses of Watt's steam engine and he also noted the slow horse-drawn canal barge movement of freight, particularly iron ore.

The many unsuccessful efforts to build a steamboat had not produced the proper shape of the hull, particularly of the bow; nor had they taught what propelling means to use, the relative proportions of such means to bow area, or how to transmit engine power to the propelling means. Fulton learned all he could of these unsuccessful efforts before he set about making his own designs. He made tests on a four-foot model driven by clock springs to determine the proper hull shape. He also found that the paddle area had to be two times the bow area. He worked out tables showing the power required to move boats of different sizes at different speeds.

Fulton's designs and experimental data convinced Livingston, then ambassador to France, that a successful steamboat could be built. The first test boat sank in a storm on the Seine, but the machinery was retrieved and was used in a second boat which ran about four miles an hour and maneuvered easily. Encouraged by the successful tests, Fulton and Livingston decided to build a boat for commercial use on the Hudson. The

* This is the second of four articles describing the 19 most famous American inventions, the background of their inventors, and the financial returns derived from them.

1 4 Journal of the Patent Office Society 330.

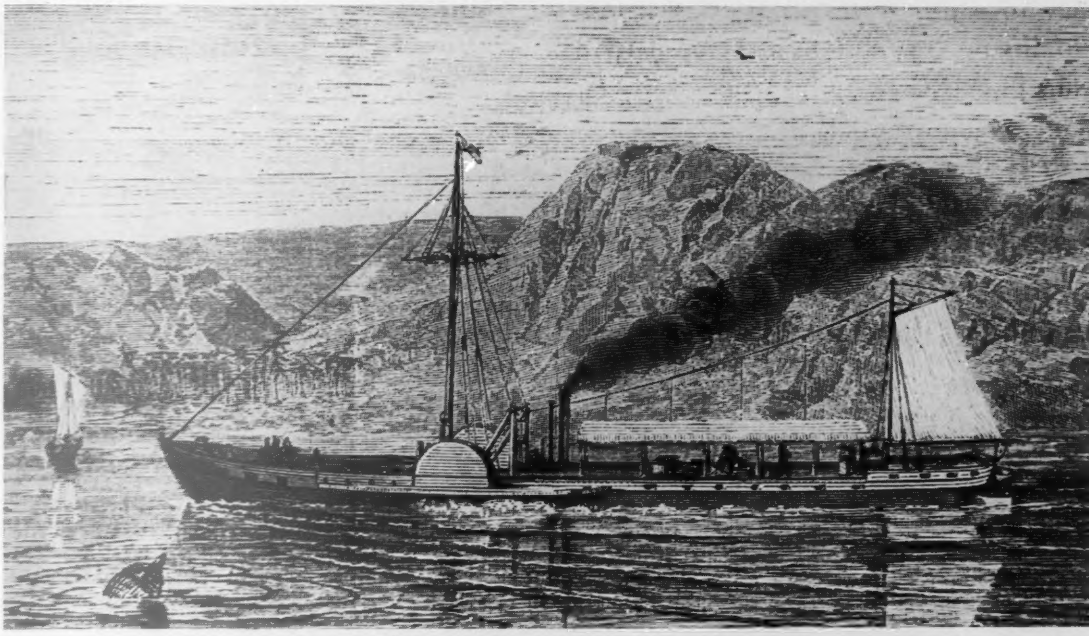
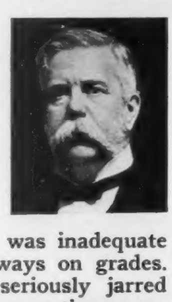


Fig. 4 — Fulton's first steamboat, the "Clermont," sailing up the Hudson. — Bettmann Archive.

boat was 150 feet long by 13 feet wide and was to draw two feet. Attempts were made to destroy the boat, and ridicule was so great that additional funds were obtainable only upon condition that the contributors' names be kept secret. On August 17, 1807, "Fulton's folly," the Clermont, ran from New York to Albany, a distance of 150 miles, in 32 hours. The Clermont was put into regular service on the New York-Albany run at a fare of $3.00 and made the trip in an average of 36 hours, compared to 48 hours for sailboats. (10 Journal of the Patent Office Society 218.)

A patent was issued to Robert Fulton for his steamboat on February 11, 1809. Fulton and Livingston built ten boats in eight years for service around New York under an exclusive franchise from New York state. The exclusive franchise was broken by Cornelius (Commodore) Vanderbilt who with Daniel Webster, his attorney, obtained a decision from the United States Supreme Court that navigable water could not be exclusively controlled by private interests.



Westinghouse's Air Brake 1869

Before air brakes, braking of trains was inadequate and resulted in overspeeds and runways on grades. Excessive braking, when required, seriously jarred passengers, caused flat wheels, and even at times generated enough heat and sparks to ignite the wooden cars of that day. The air brake is the invention of George Westinghouse, born at Central Bridge, N. Y., in 1846. His father was a manufacturer of agricultural implements, and George had access to shops and tools with which he developed his mechanical ability even though his father doubted if he would amount to anything.

Westinghouse's formal education extended to about three months at Union College, and his mechanical experience included service as a third assistant engineer in the United States Navy during the Civil War. He invented the replacer for derailed cars now in use and worked as a salesman for the company building the replacer. During his experience as a salesman, Westinghouse conceived the idea of air brakes and formed acquaintances with railroad men, all of whom however, belittled the air brake as impractical.

Train braking requires that all the brakes be applied simultaneously and uniformly. All braking must therefore be done by one man, the locomotive engineer. Robert Stephenson in 1843 devised a steam brake in which steam cylinders acted through levers to press wooden brake blocks against the wheels; but steam condensation proved an insuperable barrier, and Stephenson's invention never went into use. Hand brakes were in practical use but they were inadequate and unsatisfactory. Vacuum brakes proved unsatisfactory (76 C. D. 319.)

The original air brake invention was patented as No. 88,929, issued April 13, 1869 (Fig. 5). A steam-driven reciprocating compressor discharges air into a compressed air reservoir on each car. From these reservoirs, compressed air can be released with an "engineer's" valve to the brake cylinders for operating the brake riggings. Westinghouse found that previous failures of steam and vacuum brakes were

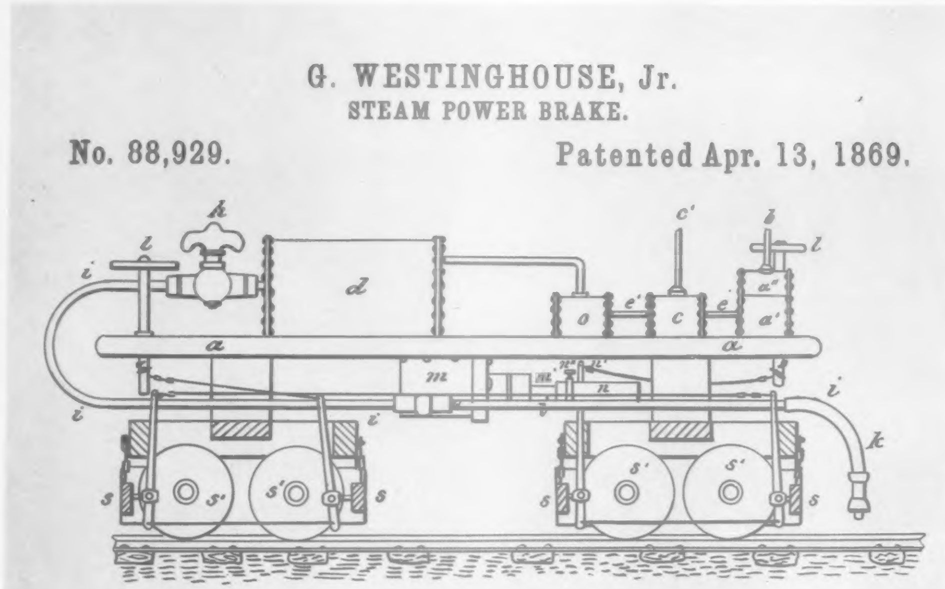


Fig. 5 — Westinghouse's Steam Power Brake.

due to the fact that the reservoir for the braking pressure was on the engine and that it took appreciable time for pressure changes to reach the last car in the train.

Westinghouse found that his original invention was also subject to a time lag, and therefore he put a reservoir on each car and placed his triple valve (patent 360,070, issued March 29, 1887) between each reservoir and the brake cylinder. The pipeline leading from the compressor on the locomotive was put under pressure which kept the valves closed. Any break in the pipeline or opening of the engineer's valve caused instant operation of each triple valve to release pressure from each reservoir simultaneously to each brake cylinder. Westinghouse prosecuted infringers under his original invention (9 O. G. 538) and under the triple valve patent (42 L. E. 1136), and in each case the patents were upheld.

The story is told that Westinghouse offered the air brake in 1868 to Commodore Vanderbilt for the New York Central Railroad and he was laughed at as a fool who would stop trains by blowing air at the wheels. The sequel to Commodore Vanderbilt's derison is supposed to be that the New York Central had to pay double the standard price of air brakes when they were finally adopted.

Westinghouse, after canvassing nearly every railroad in the country, finally persuaded the Panhandle Railroad to make a trial. It was successful, so with the aid of the Pennsylvania Railroad he equipped a freight train of 50 cars with air brakes and ran it 3,000 miles around the country to demonstrate the practicability of air brakes. The Westinghouse Air Brake Co. was organized in July, 1869, and it became the basis for the present Westinghouse Electric and Manufacturing Co. The personal financial returns to Westinghouse were entirely adequate, and he was president of over 30 corporations at the time of his death.

Wright Brothers' Airplane 1906

Wilbur and Orville Wright invented the airplane which was one of the few basic inventions immediately accepted as potentially successful, and which has brought honor and monetary return to the inventors without the necessity for overcoming much resistance. Wilbur and Orville Wright were born in 1867 at Millvale, Ind., and in 1871 at Dayton, Ohio, respectively. They received a high school education but no scientific training, and they had only the mechanical experience obtainable in their bicycle repair shop.

Their attention was directed to flying from an account of Lilienthal's death in 1896 and of his experience with gliders. They first studied everything relating to the subject of flying and then constructed at least one glider controlled by ground ropes before trying a man-carrying glider. They studied the glider balancing work done by Octave Chanute and his assistant, A. M. Herring; and they knew of Hiram Maxim's tests with a steam engine-driven plane. Of all the previous efforts, the court ruled in Wright Co. vs. Herring-Curtis Co. (204 F. 597) that, "... but all such efforts for one reason or another were abortive, and the intentions of the inventors and experimenters miscarried."

The problem was finally reduced to one of finding means for maintaining lateral balance, for steering laterally, and for steering vertically. Many hundreds of glider flights were made, and laboratory models were tested to determine air pressures on surfaces, over a period of three years before the principles shown in patent 821,393, issued May 22, 1906 (Fig. 6), were accepted as practical. The patent shows a front elevator and a vertical steering rudder which were old. However, no one had provided means for lateral balancing which the Wrights secured from warpable edges on the wings or ailerons.

On December 17, 1903, only nine days after Samuel Langley's experiments failed, a flight of 852 feet was made in one minute at Kittyhawk, N. C., in a plane propelled by a gasoline engine. The total weight of machine and operator was 925 pounds. Only five persons witnessed the flight in spite of wide public invitation, and the birth of the airplane was almost entirely ignored by the press. But the Wrights continued their development work in as great secrecy as possible, on their own time and with their own funds to avoid the distrust and ridicule of the public. Several Frenchmen, including Santos-Dumont, Bleriot, and Voisin, were now attempting to fly, but were not successful.

The Wrights offered their invention to both the United States and British governments but received no encouragement. In 1908 Wilbur took a machine to France, where newspaper ridicule did not stop him from flying 56 miles in 91½ minutes, from winning the Michelin prize of 20,000 francs, and from obtaining a French government order for 30 machines. Meanwhile, Orville was flying and even taking passengers at Fort Myer, Va., where he won a bonus of $25,000 finally set up by the United States Army for a machine flying at 50 miles per hour. The French Academy of Sciences awarded the Wrights a gold medal, and the French patents were sold for $100,000. Wilbur, unfortunately, died in 1912, but Orville went on to organize the Wright Airplane Co. in 1915. As result of World War I needs for airplanes, an aircraft cross licensing arrangement was made under which the Wright Co. received $2,000,000 in royalties under the Wright patent (3 Journal of the Patent Office Society 12).

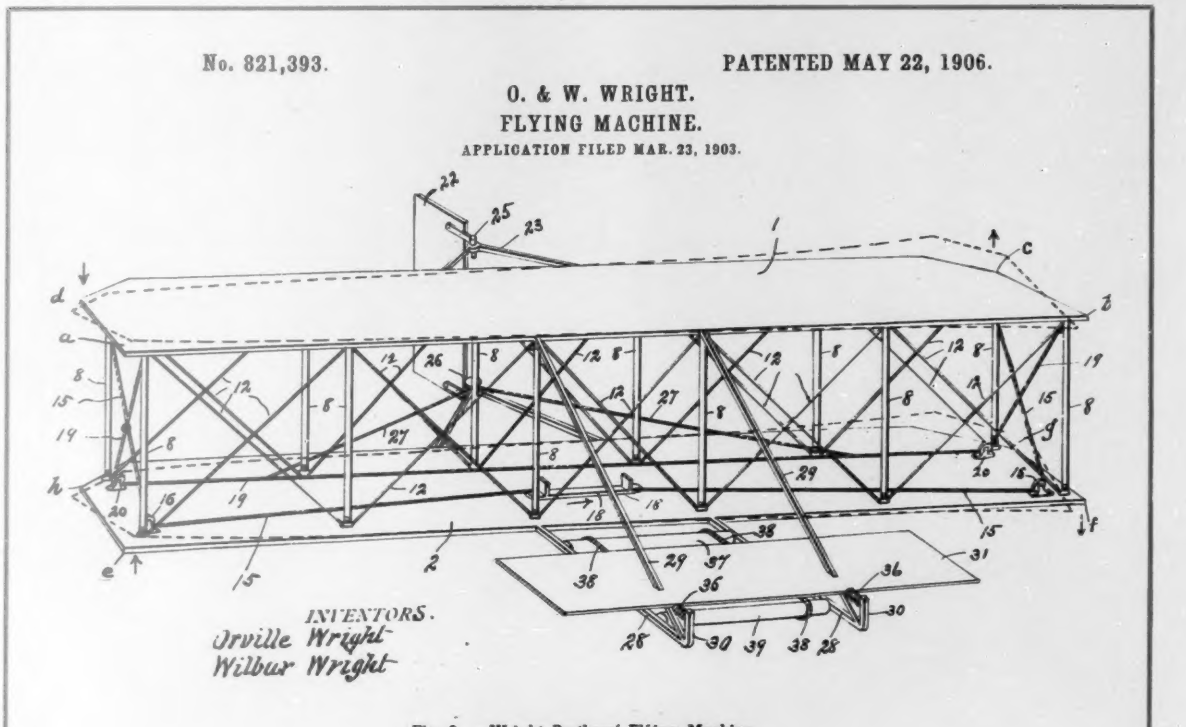


Fig. 6 — Wright Brothers' Flying Machine.

Goodyear's Vulcanized Rubber 1844

Before vulcanization of rubber by Charles Goodyear (patent 3633, issued June 15, 1844) rubber articles became a sticky, gummy mass in summer and hardened to a brittle, unyielding mass in winter. Owners of "MacIntosh" raincoats were warned against their use in either hot or cold weather.

Goodyear was born in 1800 at New Haven, Conn. His father was a hardware manufacturer, and Charles Goodyear established the first hardware store in the United States in Philadelphia for the sale of his father's goods. However, Goodyear was no business man, and the panic of 1827 put him into bankruptcy and in jail for debt for the first of many times. By 1832 Goodyear had lived in half a dozen towns and was jailed as many times for debt in spite of his many inventions improving hardware. In 1832 Goodyear first saw rubber goods at Roxbury, Mass., and made his first rubber invention. There also he first met the problem of the decomposing of unvulcanized rubber.

At this time the principles of organic chemistry were still unknown. However, in spite of an education limited to reading, writing, and arithmetic, Goodyear then and there deliberately decided to work with the improvement of rubber articles as a life vocation. In 1836, while trying to remove some unsuccessful bronze ornamentation from rubber with nitric acid, Goodyear discovered (patent 240, issued June 17, 1837) that the acid had also removed the surface stickiness from the rubber. The nitric acid method of curing of the surface of rubber is still used. The firm of Goodyear and Ballard was founded on the basis of the nitric acid rubber curing discovery, but failed in the panic of 1836.

From 1836 to 1844 Goodyear devoted all of his time to searching for a process of treating rubber to minimize the temperature effects. Goodyear borrowed from everyone to buy chemicals and food and was jailed for debt three times in eight years. In 1837 Goodyear bought a patent application (patent No. 1,090 issued February 24, 1839) from Nathaniel Hayward on a process for curing rubber by mixing it with sulphur and exposing it to sunshine. The process was successful, however, only with thin rubber sheets, and most of Goodyear's manufactured articles were returned by customers because they became sticky or rotten. By 1838 various attempts by individuals and companies to make rubber useful had been abandoned and all factories were closed.

In 1839 Goodyear accidentally dropped a piece of rubber mixed with sulphur on a hot stove and found that it charred rather than melted. For two years, while friends saved him and his family of five children from literal starvation, Goodyear worked to determine the right amount of heat required and how to apply it. During these days it was almost as difficult to convince anyone of the importance of the discovery as it had been to make the discovery itself. Within a short time after he perfected the vulcanizing process, Goodyear paid off accumulated debts of $35,000.

Hancock and MacIntosh, the British rubber manufacturers, saw a piece of Goodyear's rubber and independently discovered the vulcanizing process for which Hancock obtained a British patent, thus closing the British market to Goodyear. Goodyear's delay in obtaining his patent forced him to prosecute many infringers. In 1852, in a suit against Horace H. Day, Daniel Webster described the vulcanization of rubber before the U. S. Circuit Court of New Jersey as producing "nothing less than elastic metal" (22 Journal of the Patent Office Society 32). In another case[2] the U. S. Supreme Court ruled, "The discovery was one of great value. It is a mine of wealth to the possessors." Goodyear had to fight a total of 32 cases in the Supreme Court to protect himself and his licensees from infringements.

After discovering vulcanization, Goodyear continued his work on rubber and had issued to him about 60 patents for practically everything but pneumatic tires. After winning the major portion of his patent litigation, Goodyear took his family to Europe where he spent $30,000 displaying rubber articles at the opening of the British Crystal Palace, for which he received the Grand Council medal. Then he spent $50,000 displaying his rubber articles at the Paris Exposition. His last dollar was gone, and he was in jail for debt when the (French) Cross of the Legion of Honor was delivered to him. He lost his contest with Hancock for the British patent rights and was jailed in England for debt. He had to pawn his wife's jewelry to pay passage back home. At home he prospered for a short time, but lifelong ill health overcame him and he died $200,000 in debt.

Burton's Oil Cracking 1913

Modern automobile transportation and aviation would be handicapped or impossible for lack of fuel if William M. Burton had not discovered how to produce gasoline by cracking crude oil with the application of heat and under pressure. Burton was born in 1865 on a farm near Cleveland, Ohio, and he was educated at Western Reserve University (to which he walked seven miles each day), and at Johns Hopkins University where he received a Ph.D. degree. He was employed by Standard Oil Co. of Indiana at Whiting as its first chemist, and while so employed discovered the theory of patent 1,049,667, issued January 7, 1913 (Fig. 7).

Experiments had been made in applying pressure and heat to the distillation of petroleum by Luther

[2] Providence Rubber Co. vs. Goodyear, 76 U. S. 566.

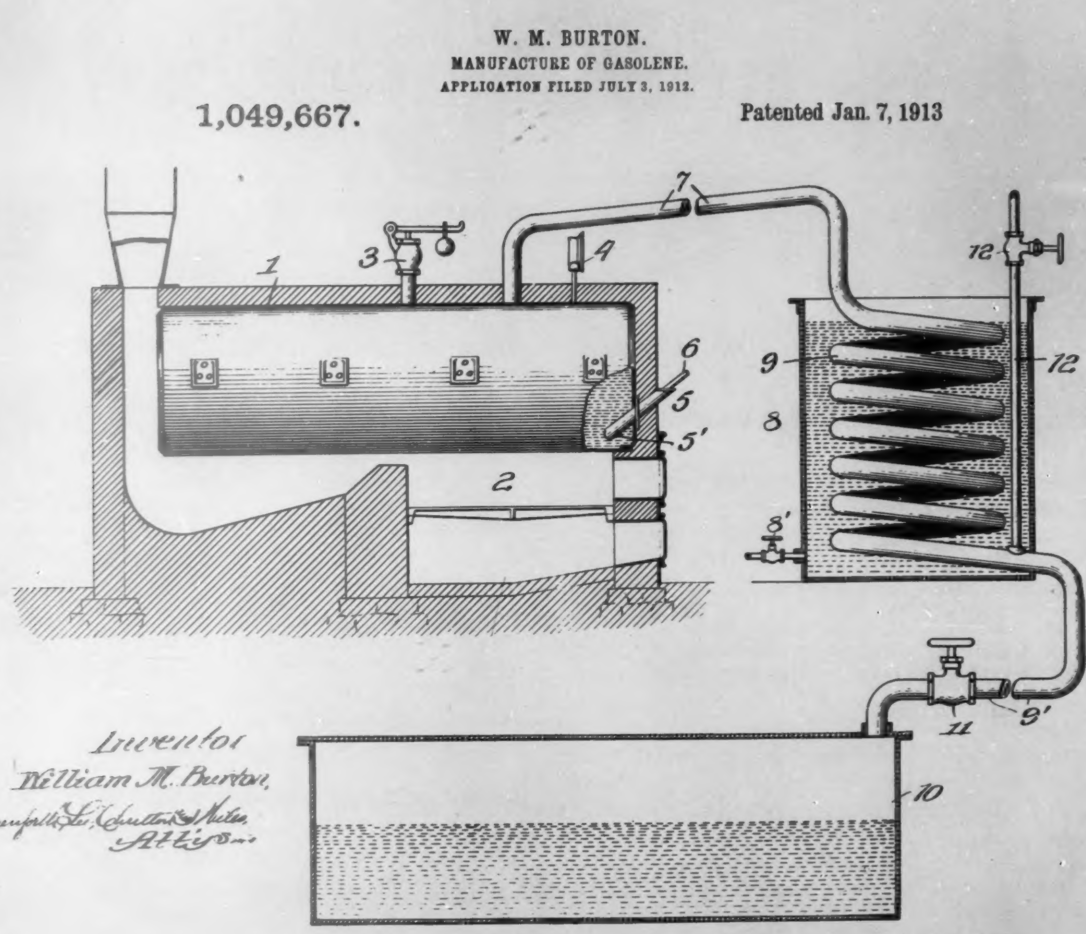


Fig. 7 — Burton's Oil Cracking Equipment.

Atwood as shown in patent 28,448 of May 29, 1860, and by Sir Boverton Redwood and Professor James DeWar (patent 419,931, January 21, 1890), but they reached no practical conclusion. Burton first tried superheating without pressure, but the yield was poor and the product unsatisfactory; he tried reagents and catalyzers, but the cost was too high. He then tried heat and pressure and found that a pressure of 95 pounds per square inch and a temperature of 725° F. would break down what was formerly only fuel oil into a lot of gasoline and a little coke.

Burton's work was done before 1913 (beginning in 1911) when these pressures and temperatures were exceedingly high for the metals then available. When the steel of the stills was softening at the high temperature and the seams were likely to part from the pressure, it took courage to continue the experiments. Even the 100-gallon pilot plant still had to be caulked because it leaked at the rivets and seams when hot.

When Burton requested $1,000,000 from the board of directors of the parent Standard Oil Co. to build a battery of production stills, he was told, "No, you'd blow the whole state of Indiana into Lake Michigan." When Standard Oil of Indiana became an independent unit, Burton again requested money. The question was asked, "Are you sure you know what you are doing?" He answered "Yes." He got the money and he knew what he was doing, as events have proved.

The return to Burton from his invention is evident from the fact that he became president of Standard Oil Co. of Indiana in 1918. He received the Willard Gibbs medal in 1918 and the Perkin medal in 1922. The return to Burton's employer, before January 1, 1921, was over $15,000,000 in royalties on the Burton process (75 L. E. 944) (6 Journal of the Patent Office Society 11).

(To be continued in next issue)

COLD DAY — OVERLOAD TRANSFORMERS?

Transformers cannot be overloaded on cold days and run at rated loads on hot days. But 30C ambient transformers in cool climates do have definite extra capacity.

W. C. Sealey

ENGINEER-IN-CHARGE, TRANSFORMER DESIGN • ALLIS-CHALMERS MANUFACTURING COMPANY

● Transformer nameplate ratings are based on the load that can be carried continuously when the surrounding air temperature is 30 C. When the ambient air temperature drops below 30 C, it is logical and correct to assume that the transformer can safely carry loads higher than its continuous kva rating.

The insulation of a transformer tends to age and deteriorate when it is heated. The higher the temperature, the faster the insulation will deteriorate. During periods of subnormal operating temperatures the loss of life of the insulation will be less than normal. When the operating temperatures are greater than normal, the loss of life during such periods will be greater than normal. Consequently, a transformer may be safely operated for a time at above normal temperatures if the loss of insulation life during this period is compensated for by operation for a sufficient time at temperatures lower than normal. The continuous temperature which would result in the same aging of insulation as the ambient temperature actually occurring during the period of time under consideration is called the equivalent ambient temperature.

Use highest equivalent temperature

The weather conditions for any given year cannot be predicted accurately. The equivalent temperature for the coming year may be greater or smaller than that of the preceding year. The safest procedure is to assume that the equivalent ambient temperature will be the highest which has ever occurred, and if higher temperatures do occur they will be only slightly higher.

Equivalent ambient temperatures can be calculated from reports of the United States Weather Bureau over a long period of time.*

An oil-immersed, self-cooled transformer may be overloaded 1 percent of its nameplate rating for each degree centigrade that the equivalent ambient temperature is below 30 C. For example, in Milwaukee, where the annual equivalent ambient temperature is only 20 C, a transformer can safely carry 110 percent of its nameplate rating throughout the year. However, during January the equivalent ambient temperature is 6 C, and consequently the transformer can safely carry 124 percent of its rated capacity during this month. But during July, when the equivalent ambient temperature is 28 C, the unit can carry only 102 percent of its nameplate capacity.

Safe loads for various localities

Values of safe loads for various localities are shown in the accompanying table. These values are based on the maximum equivalent ambient temperatures and the one degree for one percent rule for loading. For locations not listed, values may be obtained by interpolation from nearby points, taking into account the difference in the geographical features of the two locations. Either the load corresponding to the annual equivalent ambient, or loads corresponding to the individual months of the year, may be selected and used. It is obviously not correct to use the annual load for part of the year and the monthly loads for the remainder of the year, since this practice would not allow cold days to compensate for hot ones.

The values given in the table are safe values for the localities, because they represent the highest temperatures which have ever occurred. Consequently, they can be used with confidence for overloading transformers.

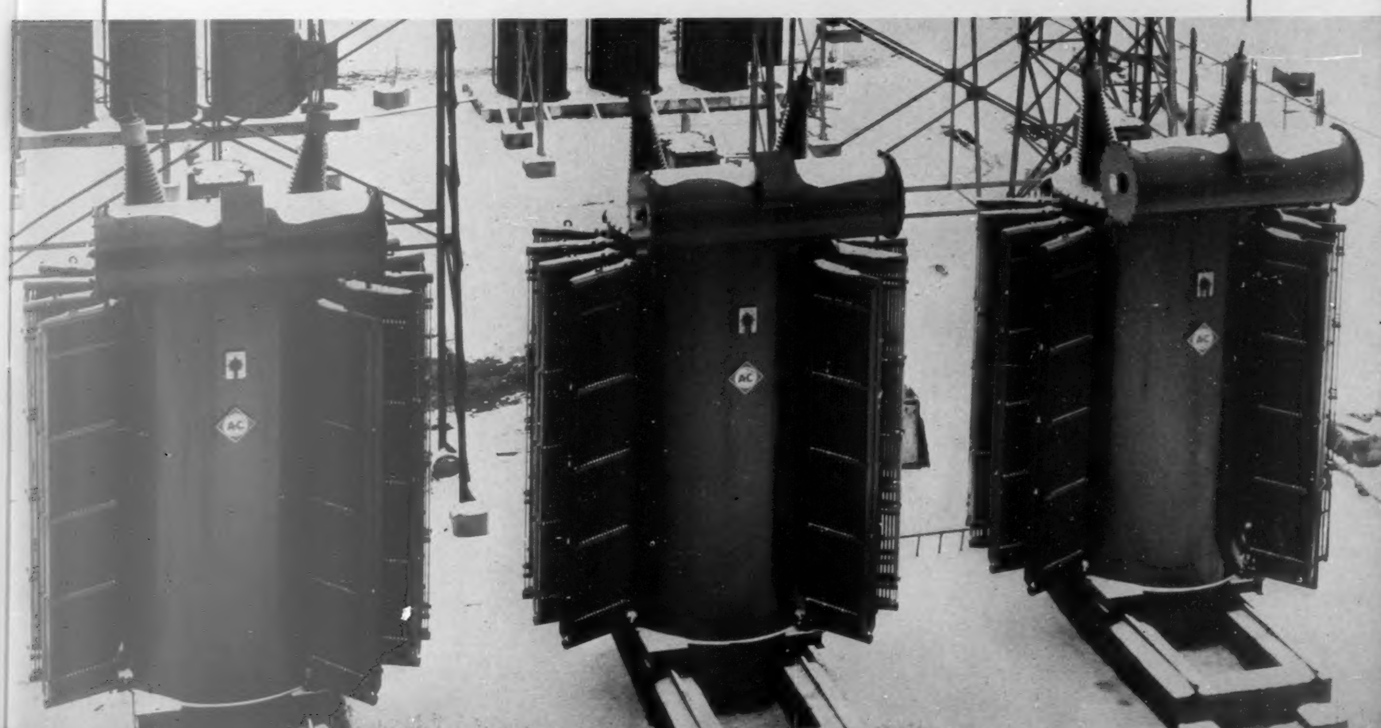
AT RIGHT: Cold weather, like this, greatly increases the current-carrying capacity of a transformer over its nameplate rating, which is based on operation at a surrounding temperature of 30 C. In such winter weather as pictured, a 45,000 kva bank of transformers can safely carry 60,000 kva.

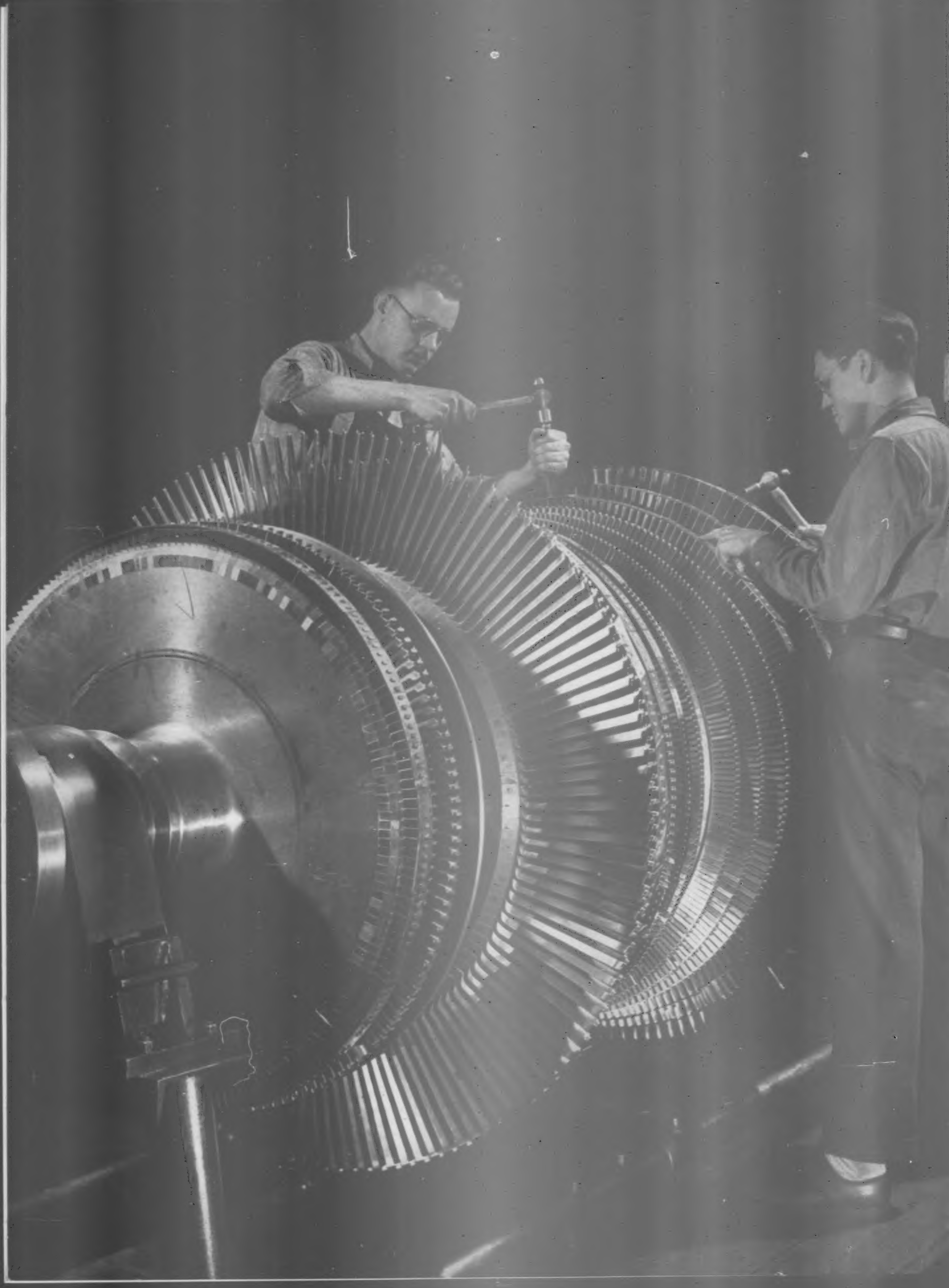
* See "Electrical Engineering," February, 1943, Page 87, *Equivalent Ambient Temperature For Loading Transformers.*

OUTDOOR OISC TRANSFORMERS

	Annual	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Atlanta	105	114	113	110	107	103	100	100	100	98	105	110	112
Bismarck	109	127	122	116	113	107	103	96	102	105	111	119	123
Boston	110	122	123	119	115	108	103	102	104	106	110	117	119
Chattanooga	106	114	113	110	108	104	100	100	100	102	105	110	115
Chicago	109	120	120	117	112	107	102	102	103	105	111	116	119
Corpus Christi	102	108	108	105	103	102	100	98	98	100	101	105	106
Dallas	102	105	110	107	104	102	96	94	94	98	104	109	112
Denver	107	118	117	115	111	107	103	100	98	104	110	115	116
Detroit	110	124	122	119	113	107	103	102	103	105	112	117	122
El Paso	104	115	115	110	106	102	96	96	98	100	105	110	114
Helena	110	120	122	119	114	110	105	101	103	108	113	119	120
Kansas City	105	119	117	110	109	104	96	94	94	102	108	112	117
Los Angeles	106	110	110	108	108	107	105	103	103	103	105	108	110
Louisville	106	114	117	112	108	104	102	98	100	101	108	110	113
Miami	102	103	105	104	102	102	101	100	100	101	102	103	103
Milwaukee	110	124	124	120	114	109	103	102	104	107	112	117	123
Minneapolis	109	128	127	118	112	106	102	100	101	106	112	121	124
New Orleans	103	107	107	106	105	102	98	98	98	100	101	107	108
New York	109	119	121	116	112	107	102	101	103	104	110	116	119
Oklahoma City	105	113	111	109	107	104	96	96	94	98	104	110	117
Philadelphia	108	118	120	114	111	107	102	101	102	103	110	115	119
Phoenix	98	112	110	107	102	96	88	82	84	90	100	108	112
Pittsburgh	107	118	118	115	110	105	103	100	101	102	109	113	118
St. Louis	105	116	117	110	108	104	96	94	96	103	108	110	115
Salt Lake City	108	124	121	117	112	106	101	96	98	104	111	119	122
San Francisco	111	116	115	112	111	110	109	110	110	108	110	112	116
Seattle	112	120	119	114	113	110	109	107	108	110	113	118	120
Washington, D. C.	107	118	118	112	109	104	102	98	100	102	109	114	118

Safe loads for transformers, based on equivalent ambient temperature (figures in percent).





FINDING HIDDEN KILOWATTS
PART II*

In planning overloads, the stator winding of an a-c generator is usually carefully considered. However, low power factor loads require heavy field excitation, and the field may not be able to take it. Here are simple ways of finding out.

Fraser Jeffrey

ASSISTANT TO CHIEF ELECTRICAL ENGINEER • ALLIS-CHALMERS MANUFACTURING COMPANY

* This is the second part of an article by Mr. Jeffrey showing how to secure greater output on equipment for the wartime purpose of conserving critical materials. Material in it has been condensed from a lecture given originally in the fall of 1942 by the author, under the title of "Securing Increased Capacity from Present Equipment." Later it was repeated under the title of "How to Secure Greater Output on Equipment to Meet Wartime Needs," and finally in 1943 it contained mention of the WPB Conservation Order L-221 and the AIEE mid-winter committee reports dealing with restrictions of ratings.

Turbo-generators

In securing increased capacity from installed generating equipment, consideration must be given not only to the amount of the load but also the "kind" of loading — that is, the power factor of the proposed additional load. If the field excitation of the generator is already maximum and cannot be further increased because of temperature limitations, then any additional load that is to be added has to be of a power factor better than that of the generator itself — probably 90, 95, or 100 percent if the generator is rated at 80 percent power factor.

Overloading with non-inductive loads, insofar as generator heating is concerned, carries the least hazard. Inductive loads of lower power factor than the generator should not be considered, unless they are relatively small, or unless the generator is well underloaded and has some field margin left.

Within rated kva, the reactive load any generator can carry is limited by the heating of its field. If a load with an increasingly lower power factor is gradually put on such a machine, a condition will be reached where the terminal voltage cannot be maintained. If the load is great enough and its power factor is low enough, even maximum excitation will not be able to maintain full voltage.

Consider the hypothetical case of a turbo-generator where it is definitely known that the steam end of the unit, as well as all of the associated equipment, is capable of carrying any true load up to as much as 25 percent overload.

From the nameplate of this generator, it is noted that, at continuous full load of 1,000 amperes 80 percent power factor, the generator is rated 60C rise on its Class "A" insulator stator coils and 85C on its Class "B" insulated rotor coils, on the basis of embedded temperature detectors in the stator windings and resistance of the rotor windings. The maximum field current is given as 300 amperes, with a temperature rise of 85C.

Assume that this machine has been in operation seven years; that it has carried approximately its full rated load at rated power factor continuously; that the actual field current under these conditions is 270 amperes and that the ambient temperature has always been approximately 40C under such loading.

Actual test readings made under installed conditions indicate that this generator has a capacity in excess of that given by the nameplate, and that under normal full load conditions the stator rise by embedded detector is only 50C instead of 60C, as indicated on the nameplate, and the rotor temperature rise by resistance with 270 field amperes is only 68C, instead of 85C.

These known conditions after installation give a definite basis for estimating possible increases in load, and determining the life expectancy of the machine under the new conditions.

Trial loadings

As a method of approach to overloading, assume that the stator might carry an overload of 25 percent. A rough check can then be made by assuming that the temperature rise in the stator is proportional to the square of the current; however, this is approximate, as it neglects the heating effect of the iron, ventilating air, etc. The actual temperature rise at full load was only 50C by embedded detector, as already noted,

AT LEFT: There are more than 25,000 metal to metal contacts in this Navy turbine spindle for ship propulsion. Faster production of these steam turbine rotors is now achieved by employing a series of broaching operations in manufacturing the thousands of bucket-type blades required.

Method	1800 AND 3600 RPM TURBO-GENERATORS																	
	Usual Temperature Rises Specified						Possible Increased Temp. Rises That Might Be Allowable						Possible Increased Total Limiting Temperatures					
	Class "A" Insulation			Class "B" Insulation			Class "A" Insulation			Class "B" Insulation			Class "A" Insulation			Class "B" Insulation		
	Stator	Rotor		Stator	Rotor		Stator	Rotor		Stator	Rotor		Stator	Rotor		Stator	Rotor	
		100% PF	80% PF		100% PF	80% PF		100% PF	80% PF		100% PF	80% PF		100% PF	80% PF		100% PF	80% PF
Thermometer	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Resistance	...	...	...	...	85C	85C	...	...	...	...	85C	85C	...	...	...	...	135C	135C
Embedded Det.	60C	...	...	60C	...	...	60C	...	...	80C	...	...	105C	...	...	130C	...	...

Fig. 6 — Possibilities for securing increased capacity from 1800 and 3600 rpm turbo-generators (Class "B" insulation for all rotors).

so the temperature rise on this new basis would be approximately

$$\left(\frac{1.25}{1.00}\right)^2 \times 50 = 78C.$$

This is beyond the 60C limit that is considered safe for operation.

Therefore, by trial it will be found that a 9 percent additional current load gives

$$\left(\frac{1.09}{1.00}\right)^2 \times 50 = 59.5C \text{ rise.}$$

This is very close to the maximum safe rise of 60C. Thus, it is concluded that the maximum stator current which this generator can safely carry is 109 percent of rated current.

Likewise, the known temperature rise of the rotor by hot resistance from actual loading at 270 amperes was 68C. The same method of approximation for estimating temperatures can be used. At the maximum current of 300 amperes, the field winding temperature rise is

$$\left(\frac{3.00}{2.70}\right)^2 \times 68 = 84C \text{ rise.}$$

Thus, the maximum field temperature will be within the rise of 85C, which is considered a maximum for the fields of turbo-generators, as indicated in Fig. 6.

The conclusion is that when this generator is overloaded, the stator current must not exceed 109 percent of full load current, and the field current must not exceed 300 amperes.

It is much safer, however, to take a number of actual load test points of the temperature rise of both stator and rotor windings and plot these in curve form. Taking a few isolated test points is not recommended because errors are likely to creep in and they may lead to erroneous and dangerous conclusions. Conditions are always changing — the ventilating ducts in the stator and rotor may become clogged with dirt, the air filters may become dirty, etc. — so the curve of temperature rises should at least be point checked at frequent intervals.

Kinds of load

The way in which these limits of stator and rotor current affect the loading of the generator is shown in Fig. 7.

Point "A" is the rated load point, 1,000 amperes at 80 percent power factor with 270 amperes field excitation. The line OA can be considered as a vector representing rated full load current in its proper phase relationship.

At 80 percent power factor, the 1,000 amperes can be divided into an OB power component of 800 amperes in phase with the voltage, and a 600 amperes component, OC, in quadrature with the voltage, representing the "watt-less" kva.

The stator current limit of 1,090 amperes, which

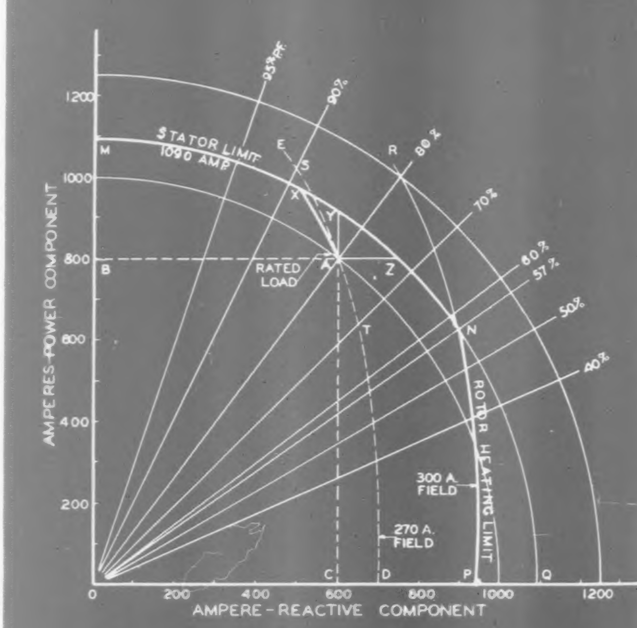


Fig. 7 — Rotor and stator load limits of a turbo-generator.

was determined in the manner shown above, can then be represented by the arc MNQ drawn with O as its center.

The curved lines DAE and PNR represent the field heating limits for 270 and 300 amperes respectively, as discussed previously. These curved lines are established from the known excitation characteristics of the machine under consideration and vary with different generators. For purposes of trial loadings, they can be based on average conditions that can later be verified by actual tests.

It will be noted that the curved line EAD intersects the 90 percent power factor line at S with a primary current of OS; the 80 percent power factor line at A with a primary current of OA; the 70 percent power factor line at T with a primary current of OT; and so on. This means that, with a field of 270 amperes, the excitation characteristics of the machine are such that rated voltage can be maintained with different primary loadings at various power factors.

These loadings at different power factors merely represent the general characteristics of the generator, and they do not mean that all such loadings can be maintained under constant load conditions because stator temperature rise limits the primary current that can be carried safely. For example, the line RNP, representing 300 amperes, field excitation, intersects the 80 percent power factor line at 1,250 amperes. This current is beyond the safe operating limit of the stator.

Limit for stator and rotor

Since the maximum load, from a temperature standpoint, is governed by the limits of stator current and rotor current, the maximum loading of the generator must terminate on the heavy line MNP. In the region from M to N, the load is limited by the stator heating; and in the region from N to P, the load is limited by rotor heating. Thus, at point N, the generator can carry 1,090 amperes at 57 percent power factor with a field current of 300 amperes. This load represents the tentative limiting condition for both stator and field.

Additional loads, superimposed on the normal rated load of the generator, can be represented by a vector such as AY for a unity power factor load, AZ for a zero power factor load, or AX for a leading power factor load. The total resulting load on the generator, in terms of primary or stator current, would be OY, OZ, and OX respectively.

This hypothetical generator has a greater maximum field limit than would normally be required, and the loadings shown are within the working range of the field limit of 300 amperes. Such loads will naturally require field currents of less than 270 amperes for the leading power factor loading, OX, and greater values for the OY and OZ loadings, but they are still within

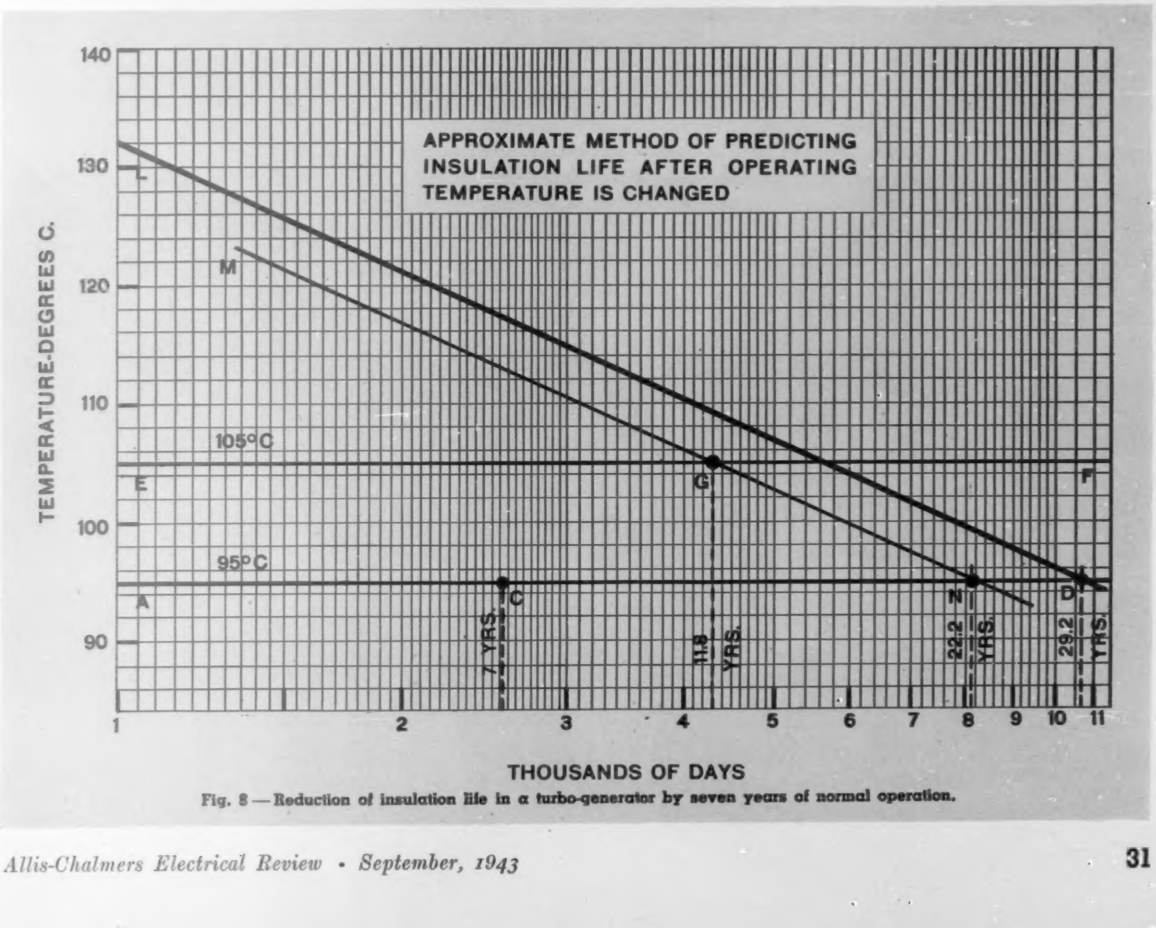


Fig. 8 — Reduction of insulation life in a turbo-generator by seven years of normal operation.

the 300 ampere field current limit. This condition applies to this particular generator only.

These factors make it apparent that great care must be exercised in the "kind" of additional loading that is put on a generator. The examples show the possibilities for adding a 100 percent power factor load AY to give an overall power factor of 83.5 percent for the generator; a zero power factor load of AZ gives an overall power factor of 73.5 percent; and a 94 percent leading power factor of AX results in an overall power factor of 85.5 percent for the generator.

Actual testing

The only accurate way to find new temperature rises under the new loading conditions is by means of an actual load test. Where large additional loads seem feasible, step by step incremental loading and actual testing is far safer than adding a proportionately larger load at once.

Relatively small blocks of power, however, would not have to be tested out in split-up units. In all cases it is advisable to actually test for temperatures rather than use rule of thumb methods.

The proper amount of load at the correct power factor may be hard to find. It would seem that in those cases where relatively small amounts of load are available, it would be advantageous to build up more non-inductive load, provided the stability of the generator would still be satisfactory.

System stability

Increased kw loading of any generator invariably increases its chances of falling out of step during system disturbances. The danger of losing synchronism is still greater if an increase in load results in better power factor. Stability must also be given careful study, because, if the new loading appears unsatisfactory from a stability standpoint, certain changes in operating procedures, relays, circuit breakers for limiting the fault duration, and improved control of the generator exciter may be necessary.

Insulation life

Let us go back now to the turbo-generator to consider the life of the stator windings under the increased loading of 9 percent, where it was expected the temperature rise would increase from 50C to about 60C, as measured by embedded temperature detectors.

At full load, 50C rise + 40C ambient + 5C hot spot gives a total limiting temperature of 95C, which represents the condition at which the machine has been operating for 7 years. From Fig. 8, an insulation life of approximately 29.2 years could be expected if the machine had been allowed to operate continuously on this normal 1,000 ampere load. The insulation life line LD is the same as the heavy middle line shown previously in Fig. 3.

In the 1,090 ampere overloaded condition 60C rise + 40C ambient + 5C hot spot gives a total limiting temperature of 105C for the maximum load that can be applied to this machine. The question now is to find out how many more years this generator can operate at this higher temperature before the insulation life is completed.

Line AD (Fig. 8), representing a temperature of 95C, intersects the insulation life line LD at 10,650 days (29.2 years).

If it can be assumed that the insulation's life is expended uniformly as time goes on, then after 7 years at 95C, represented by the line AC, the life would be

$$\frac{7}{29.2} \times 100 = 24\% \text{ gone, or,}$$

$$100\% - 24\% = 76\% \text{ of the life remains.}$$

Therefore, the life left is 76 percent of 10,650 days = 8,100 days or 22.2 years. This is represented by the line AN. Since the insulation life (abscissa) is plotted on a logarithmic scale, a line MN, when drawn parallel to LD through the point N, represents 76 percent of the life shown by line LD. The additional life that can be expected under the increased loading (105C) is determined by the intersection of the line MN with the 105C line EF at point G. This is approximately 11.8 years.

Further life changes

Similarly, any other condition of increased or decreased temperature can be approximated by first determining what percent of the total insulation life has been used up at the initial temperature and drawing a line corresponding to line MN based on this percentage. The additional life of the insulation after the temperature has been increased or decreased can be determined from the intersection of the new line with the horizontal temperature line in question.

The life curve can be worked out for all kinds of different loadings, either ascending or descending, and this is a simple and easy method of approximation.

The procedure for synchronous motors and definite pole a-c generators is exactly the same as that for the turbo-generators. The maximum field heating has to be first ascertained before additional loads can be applied to the stator winding.

Induction motors

Induction motors can be approached differently, because there is no exciting field on the rotor to be considered.

Most induction motors are built for 40C rise by the thermometer method for continuous full load. A "service factor" of 1.15 is built into most of these machines, which means that 15 percent overload can be carried continuously without injurious heating. Just what temperature rise constitutes injurious heating is not defined. Ordinarily, a motor that operates at continuous full load with 40C rise (by thermometer) might easily be expected to have approximately 50C or more rise on 15 percent overload, or at a total temperature of 105C in a 40C ambient temperature. This 10C higher continuous operating temperature is apt to cut in about half the expected insulation life.

AT RIGHT: A special milling machine is used to finish this 2,300 pound transmission casing for a crawler-type tractor.

The life curve would show a reduction from 29.2 years to 15 years.

With 25 percent overload, as recommended by WPB and the AIEE sub-committee, and a possible temperature rise of 60C by thermometer, the total temperature would be about 115C, and the insulation life would be cut from 29.2 years to 8 years.

In war plants such loading may be fully warranted. However, good judgment is always needed. Other factors affecting the motor loading, such as starting torque, maximum torque, etc., must be fully considered. Sometimes these factors, rather than the continuous rating, determine the motor size.

D-C motors and generators

Direct current machines can be overloaded in much the same way as induction motors. Most of these machines, in the general purpose class at least, are built for 40C rise by thermometer for continuous full load, but they also carry a "service factor" of 1.15. At this increased load the commutation is expected to be reasonable, but the insulation life will be cut approximately in half. Large equipment and special applications should receive individual consideration.

The War Production Board Conservation Order L-221 limits the ratio of the rating of d-c open type 40C motors to not more than 87 percent of the determined load. This is equivalent to a factor of 1.15. The AIEE sub-committee report of January, 1943, dealing with restricted ratings for the same type of equipment, limits the ratio to the same factor of 1.15. Both of these limitations refer more to new equipment to be purchased rather than to existing equipment.

Conclusion

The possibilities of getting more capacity from present equipment deserve the serious consideration of all manufacturers, operators, and users of electrical equipment. Primarily to conserve critical materials now in wartime, full advantage should be taken of extra output available, even though life of the equipment may be shortened as a result.

Naturally, such efforts should be made along reasonable lines, however, preferably in the manner of the step by step method already explained. If such an approach is taken, and too great an increase in capacity is not effected at one time, unforeseen difficulties will not be encountered and costly breakdowns will be avoided, especially in the case of large generators already installed.

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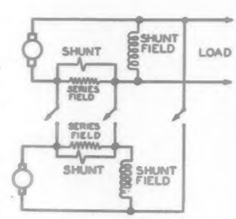
WHAT'S THE ANSWER?

Question— Two compound wound d-c generators with equalizer connections are not sharing the load properly. Changing the series field, shunt resistance doesn't help. What would you suggest? — P. O.

Answer— When two compound wound generators are in parallel, the series fields and their shunts are paralleled by the equalizer connection. Thus, one shunt cannot be adjusted without changing the characteristics of both series fields.



To obtain the best possible load distribution between two such generators, it is first necessary to apply full load to each generator separately, with its series field short circuited, and adjust the brush position to give the same drooping characteristic for each machine. Then the series field can be connected in and the series field shunt adjusted for the compounding required, still loading each generator alone. Measure the voltage drop at full load across the series field after this adjustment.

It will be necessary to add a series field resistor in the negative side of the generator having the lowest voltage drop in the series field at rated load. The generators can then be paralleled.

Question— What is "arc-blow," and why does it affect d-c welding and not a-c welding? — L. W. F.

Answer— "Arc-blow" is a phenomenon caused by the existence about an arc of two magnetic fields, which may oppose or attract each other, depending upon the direction of the current. One magnetic field surrounds the metallic arc, since it is a conductor of electricity like the welding cable itself. At the same time, another field is set up by the current being carried through the work piece to the arc. As a result, in d-c welding, the arc (a flexible conductor) is twisted out of its normal path, making it difficult to deposit metal in the desired place, especially in confined areas and at higher currents.

In a-c welding this problem does not exist. Here, eddy currents, set up symmetrical with the arc in the work, break up the magnetic field, because the arc current and the eddy currents cannot occupy the same space at the same time. And with the absence of the arc-blow problem, welding speeds are increased from 10 to 30 percent.

"What's the Answer?" is conducted for the benefit of readers of ELECTRICAL REVIEW who have questions on central station, industrial or power plant equipment. Send all questions to the Editors of ELECTRICAL REVIEW.

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2 Low striking voltage at high amperage.	Saves power for you. No need for high voltage at high currents. Raises power factor — cuts power input.	YES (65 volts)	NO (75 volts)	NO (75 volts)	NO (75 volts)
3 High striking voltage at low amperage.	Strikes arc fast. Gives you high, yet safe voltage necessary. Makes a-c welding easy at low currents.	YES (78 volts)	NO (72 volts)	NO (75 volts)	NO (75 volts)
4 Takes less than 300 sq. in. floor space.	Small size saves valuable space on crowded shop floors . . . makes it easier for you to move and handle the unit.	YES (281 sq. in.)	NO (361 sq. in.)	NO (398 sq. in.)	YES (288 sq. in.)
5 Contains less than 5 wearing parts.	Cuts maintenance to simple lubrication twice a year. Less chance for wear means longer service, lower upkeep.	YES (4 parts)	NO (8 or more)	NO (6 or more)	NO (8 or more)
6 Low original cost (no rotating element).	Simpler construction of a-c welder cuts purchase price to around 65% of what you would pay for a d-c welder!	YES	YES	YES	YES
7 Wide welding range of over 200 amperes.	You can weld thin sheets . . . yet have capacity for heavy plates, too. You can use rods from 1/16" to 1/4" in size!	YES (220 amp)	YES (215 amp)	NO (195 amp)	NO (195 amp)
8 Reconnectable for 220-440 & 208 v., 60 cycle.	Gives you full capacity at low voltages where lines are long and isolated. Can be used on *any* standard a-c voltage!	YES	NO (220 or 440)	NO (220-440 only)	NO (220-440 only)
9 Over 85% efficiency at normal loads.	You enjoy *full* benefits of a-c welding: lower power loss, high power factor, lower operating costs!	YES	NO	YES	YES
10 All settings within six control turns.	Saves welding time. Welder can make simple adjustment from high to low amperage current quickly and easily.	YES (6 turns)	NO (50 turns)	NO (30 turns)	NO (15 turns)
11 Movement of variable part 2" or less.	Cuts wear and maintenance to a minimum. Reduces hum and vibration Contributes to trouble-free operation.	YES (1 inch)	NO (9 inches)	NO (6 inches)	YES (2 inches)
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